Sandia National Laboratories

A History of Exceptional Service in the National Interest

SAND97-1029

front cover photo: A 1969 aerial view looking southeast over Sandia New Mexico's main technical area.

back cover photo: Test drop of a joint test assembly at Tonopah Test Range.

ERRATA

P. 20, photograph: “mechanical assembly had a monorail and hoist to move weapons from the building to trucks” should read “mechanical testing had a monorail and hoist to move weapon parts, inert weapons, and prototypes.”

P. 56, photograph: Tom Fox is seated at the console and Marty Snyderman is in the left background.

P. 57, line 12: “IBM 604, Elecom 125, CDC 3600, and IBM 7090” should read “IBM 604, Elecom 125, IBM 704, CDC 1604, CDC 3600, and IBM 7090.”

P. 69, photograph: the individuals in the cold chamber are Wesley Haig and Charles Grassham.

P. 84, photograph: first sentence of caption should read “Kingfish launch during Operation Fishbowl of the Dominic test series.”

P. 98, bottom photograph: caption should read “Carl Murphy uses a commercial laser to develop nondestructive testing techniques using holographic interferometry.”

P. 111, bottom photograph: “the room-size IBM computers” should read “analog computers.” The seated individual is Lowell Watkins.

P. 163, bottom photograph: image should be rotated 90 degrees to the right.

P. 243, top photograph: the engineers are John Smelser, Carl Curtis, and Hovey Corbin.

P. 295, photograph: caption should read “Launch of a two-stage, Sprint-powered, reverse ballistic rocket sled built for impact testing of the W87/Mk21 mock weapon development unit at Sandia's 10,000-ft. Sled Track." (February 15, 1986)

SANDIA NATIONAL LABORATORIES

A HISTORY OF EXCEPTIONAL SERVICE IN THE NATIONAL INTEREST

SANDIA NATIONAL LABORATORIES:

A HISTORY OF EXCEPTIONAL SERVICE IN THE NATIONAL INTEREST

Leland Johnson

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Photo editing by Myra O'Canna

Designed by Jan Gaunce

Sandia National Laboratories
Albuquerque, New Mexico
Livermore, California

This study was performed at Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

In an effort to make this study easy to read, acronyms are generally avoided. When unfamiliar acronyms must be used, they are explained in the proximate text. Use of professional titles and distinctions of military rank are eschewed.

SAND97-1029

Sandia National Laboratories
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Contents

Foreword

Although most of my early career was spent at Los Alamos, I often worked with the men and women of our sister laboratory — Sandia National Laboratories. Early on I came to value and respect their dedication to the mission of safeguarding our nation's security, and I was particularly impressed by how focused Sandia's people were in harnessing outstanding science and technology to meet national needs. From the earliest days of the Cold War to the more diverse threats we face today, after the collapse of the Soviet Union, Sandia proved superior to all others in the speed at which technology could be applied to counter the present and emerging threats.

Since I joined Sandia in 1990, and especially when I became Sandia's President in August of 1995, I have come to appreciate at a much deeper level the commitment that individual Sandians give to the phrase "exceptional service in the national interest." I see it as the driving force for our motivations, our ethics, and our legendary "devotion to duty."

Sandia National Laboratories faces institutional challenges today that closely parallel the confusion at national levels. As the nation's leaders wrestle with the changes, particularly defense downsizing, which has been occurring since the end of the Cold War, Sandia has downsized and reengineered itself as a leaner, more agile laboratory. But at the same time we are motivated to attempt even higher levels of contributions to the nation by the realization that there are other threats arising, as well as new opportunities, as a result of the global emergence of many other nations.

One thing remains clear: we will continue to be one of the primary providers of the science, engineering, and technology needs to ensure the security of the United States. This will include our historic role in creating and designing the major portions of the nation's stockpile of nuclear weapons and our responsibility for system safety, security, and control for these weapons systems. Our science and technology base, built for the weapons missions, will continue to provide us the skills to solve important national problems in many other areas: energy and environment, counterterrorism, arms control, nonproliferation, and nuclear waste storage. These supporting missions will continue to make Sandia one of the most interesting research institutions in the free world.

As we approach the fiftieth anniversary of the founding of Sandia as a separate laboratory, there are almost no workers who have been with the Laboratory for its complete history. The torch has indeed been passed to a new generation of engineers, scientists, and support staff. It is for us here now to carry forward within us the spirit of that history of great and small accomplishments that have made the Sandia National Laboratories among the nation's greatest treasures. This volume will help us in that remembrance.

Paul Robinson

On the eve of the 21st century, Sandia National Laboratories is in a great state of flux. It, along with the rest of the nuclear deterrent complex, is being buffeted by changes resulting from the end of the Cold War, the dissolution of the Soviet Union, and a major event in fiscal policy — the imperative to balance the budget.

I look forward to a new and exciting mission in the 21st century for Sandia and the other national labs. This mission will be science-based stockpile stewardship tied tightly to their capabilities and the defense needs of the nation. For the next 20 to 30 years they will have responsibility for monitoring, maintaining, and assuring the safety, reliability, and effectiveness of 4,000 to 5,000 nuclear weapons.

This mission is a continuation of the historic role Sandia assumed right after the Second World War. The dedication and exceptional service in the national interest of Sandians past and present was a major factor in the ending of the Cold War.

This history of Sandia Labs comes at a crucial juncture — on the eve of its 50th anniversary in 1999, which will launch the Labs into the challenges of the 21st century. In the words of Sandia's history program: "It's hard to know where you're going if you don't know where you are and how you got there." It is imperative for current and future employees as well as the public at large to be aware of Sandia's history so they can be prepared for a challenging future.

Senator Pete Domenici

Man is slightly nearer to the atom than to the star ... From his central position man can survey the grandest works of Nature with the astronomer, or the minutest works with the physicist.

Sir Arthur Stanley Eddington

Born with the atomic age, Sandia's history is one with the atom and the star; its legacy is the stuff of quietly spectacular progress. This volume is devoted to the work done here, and the people who built such an enviable reputation of excellence at this outstanding national laboratory.

Sandia is poised to move into the next century, prepared to continue its leadership role in meeting the defense and economic challenges of our nation. This book offers a look at its valuable past, and a glimpse into its invaluable future.

Senator Jeff Bingaman

As a representative of New Mexico's First Congressional District, I know what an important role Sandia National Laboratories plays in our community. I am also acutely aware of Sandia Labs' vital role, historically was well as for the present and future, in our national defense. It is important to ensure that the history of lab success in its national security mission is carried forward into the future for the continued benefit of the nation and New Mexico.

So a general history of Sandia is a highly welcome publication. It not only places into focus the Labs' major role in regional development, but also its unique engineering support for the other two major nuclear weapons laboratories — Los Alamos and Lawrence Livermore.

As we approach the end of the millennium, the roles of the national labs are undergoing close scrutiny, and balancing the federal budget while maintaining such national treasures as Sandia will not be easy. But I anticipate that this History of Sandia will contribute to a better understanding of just how crucial our labs have been and must continue to be. That will, in turn, contribute to a better-informed discussion on behalf of our national security future and the future of Sandia National Laboratories.

Sandia is to be commended both for the excellent and unique technical expertise it provides, and for supporting a history program such as this, which will educate both this generation and the next about the nature of Sandia's work and its continuing importance as America moves into the 21st century.

Representative Steve Schiff

Acknowledgments

Where is Sandia and what does it do? This often was the first question asked of Sandians meeting with industrial and university leaders during the 1990s. A legacy of its early history when obscurity seemed desirable to protect its highly classified nuclear weapon designs, this public information gap did not trouble Sandians for most of the Labs' history. As it matured into the largest multiprogram laboratory in the Department of Energy pantheon, however, its vague public image sometimes handicapped Sandians who sought transfer of its technology to private industry and universities.

This book seeks to redress Sandia's traditional low profile by gathering the principal events and key people that propelled the Labs' impressive growth between 1949 and the present. This work would not have been possible without the dedication, time, and support of hundreds of Sandians — both past and present. While it is not possible to name them all, I do wish to highlight a few special individuals.

Sandia's History Advisory Panel, chaired by Max Newsom, provided direction and resources for the study, and I am grateful to its members for their guidance and encouragement. Serving on the Panel were James Schirber, Glen Kepler, John Hogan, Glen Otey, Jim Ney, John Taylor, Bill Nickell, Ruth David, Tom Edrington, Jim Wright, Paul Longmire, Dick Lynch, Wendell Weart, Herb Pitts, Nancy Pruett, Joe Stiegler, Rob Rinne, Tom Sellers, Don Rigali, Virgil Dugan, and Nigel Hey.

Valuable assistance in identifying and locating sources came from Diana Zepeda, Rick Ray, and Joni Hezlep of the National Atomic Museum and from Liz Kuehl, Sharon Gorman, Connie Souza, Julie Kesti, Susan Stinchcomb, and Sally Landenberger of the Technical Library and Documents group, who cordially hosted the author as well during the formative research phase.

For continuing management, funding, and support of the Sandia History Program, a debt of gratitude is owed to Nancy Pruett, Anna Nusbaum, Myra O'Canna, Carmen Ward, Dottie Sheppard, Linda Cusimano, Dave Gaynon, Sandy Tonnesen, JoAnn Tamashiro, David Barton, Rebecca Ullrich, Joe Garcia, Milrene Goodloe, Vicky Kulsic, Kathryn Olson, Paul Gallegos, Peg Warner, Cathy Pasterczyk, Tammy Garcia, and Santiago Gurule of the Recorded Information Management department. Without their enthusiastic support, this endeavor would not have been completed. To Carolyn Roberts, Denise Sobolik, Karl Lee, Laurie Cady, Jim Griego, Edwina Herrera-Ortiz, Kathy Manzanares, Theresa Stuhlmann, Alan Zaben, and especially Teresa Vigil of Millican & Associates, the author must express as well his personal appreciation for their friendly contributions.

Paul Walker, Chuck Parrish, Jim Siburt, and Bill Baldwin of the U.S. Army Corps of Engineers and Danny Schaffer and Don Traugher of Oak Ridge National Laboratory provided useful documents and information, and Sandians John Hogan and Clyde Layne supplied instruction in nuclear weapons technology. Harriet Goodness offered friendship and critical reviews. Dick Craner performed classification reviews; Gwen Pirtle assisted with the history of Building 828 and Tech Area II; Ed Rosch and Doug Henson funded study of individual weapons; Jack Simchock, Jim Wright, and Ray Jones managed outdoor seminars; and Redd Eakin and Juanita Sanchez of Community Relations provided valuable speaking opportunities.

Enlightening concepts came from research by Bill Stevens, Jim Knecht, Phil Owens, Harold Rarrick, Dale Ruth, and especially John Dickinson; and I am much indebted to Necah Furman, Karen Shane, and the late Ted Alexander for their pioneering historical studies and archival collection. Dick Jones, Paul Cooper, and John Dickinson offered guided tours of Coyote Canyon; Barry Schrader, Mark Connor, Gary Drummond, and Jim Wright hosted a tour of Livermore; and Wayne Lathrop and friends demonstrated Sandia's activities at Tonopah Test Range. These were eye-opening experiences for which heartfelt thanks are proffered.

Jan Gaunce provided the artistic layout and design, while Bill Laskar, Randy Montoya, and other Sandia photographers served as primary sources of illustrations. Sandia's story is better told through their pictures than through our words. Myra O'Canna collected and organized these graphics for use in this history and for archival purposes. Inspirational support from Tom and Phyllis Moody, Harry and Tammy Riser, Paula McAllister, Loreta Crawford, Joan Cahill, and Rik and Richard Simari of Mountainside associates proved salutary at critical points.

Special thanks are owed to Sandia retirees Bob Henderson, Ray Powell, Randy Maydew, Bob Peurifoy, Leon Smith, Mert Robertson, Fred Vook, Robert Thompson, Herb Filusch, Alan Ayers, and others listed in the bibliography for formal interviews, informative chats, and kind cooperation. They and other Sandians made the history which this study outlines.

This brief outline of Sandia National Laboratories' heritage is intended to provide a better understanding of its present, to be a guidepost to its strengths, and to lay out a road map for its future. I hope as well that readers perusing these pages can share some of the joy, excitement, and pride that have accompanied Sandia's journey of discovery and service.

Leland Johnson

In January of 1995, Leland Johnson left Sandia. The History Program staff took over the editing and rewriting of the draft he had produced of *Sandia National Laboratories: A History of Exceptional Service in the National Interest.* John Taylor of the policy and analysis research department spearheaded our efforts, coordinating reviews from members of the History Advisory Panel, and doing a great deal of the rewriting required to accommodate the reviewers' recommendations.

The second draft of the book was reviewed by the History Panel and several individuals chosen for the breadth and depth of their knowledge about Sandia's programs. We would like to thank Ron Andreas, Gary Beeler, Larry Bertholf, John Bode, John Crawford, Glenn Fowler, Roger Hagengruber, Dan Hartley, Bob Henderson, Jack Howard, Randy Maydew, Bill Myre, George Samara, Heinz Schmitt, Leon Smith, Sam Varnado, Fred Vook, Luke Vortman, Jack Wiesen, Charlie Winter, and Gerry Yonas. Next, sections of the draft were sent to 173 subject area experts — identified by John Taylor and Max Newsom, the History Advisory Panel chair, in consultation with several other Panel members. Of those 173, 114 responded. Their names are included in the bibliographic essay in the sections concerning topics they reviewed. Their contributions were invaluable — they confirmed many facts, corrected some errors, and helped guide us to the appropriate names of individuals to mention in each section. We are grateful to them.

We received a great deal of assistance in writing and editing the sidebars. Bob Henderson provided the text from his experience at Trinity; Kay Sanderville reviewed the medical sidebar; Harold Jeblick inspired the quality assurance sidebar; Orval Jones added information to the sidebar on Sandia's educational programs; Randy Maydew supplied the information for the Palomares sidebar; John Shunny wrote most of the *Lab News* sidebar; Alicia Cloer provided research for and reviewed the sidebar on Sandia's secretaries; Karen Gillings reviewed the human resources sidebar; Julie Clausen provided text and information for the sidebar on media relations; Tom Edrington gave extensive information for and reviewed the stockpile evaluation sidebar; Wendell Weart supplied information and reviewed the WIPP sidebar; and Dick Craner drafted and reviewed the sidebar on classification.

In addition to those who were asked to review particular sections, we would also like to thank John Dickinson, Herb Filusch, Bob Henderson, Jack Howard, Diana Mares, Tom Martin, Randy Maydew, Dave Northrop, Phil Owens, Harold Rarrick, Bill Stevens, Bonnie Vigil, and Jim Wadell for answering questions quickly and with good humor on a variety of topics ranging across Sandia's history.

Because of their familiarity with so much of Sandia's history and the general agreement that their judgment is reliable, Orval Jones and Charlie Winter were asked to review the final draft of the book. They both put in long hours and provided us with extensive comments. Their efforts have made it a better book and we thank them.

The vast majority of the photographs in the book were taken by Sandia's photographers. We would like to acknowledge the fine work of Louis Archuleta, Jim Bechdel, Ben Benjamin, Walt Dickenman, Louie Ernie, Robert Ezell, Oscar Goodwin, Linda Hadley, Diana Helgeson, Gerse Martinez, Randy Montoya, Don Papineau, Jim Pennington, Mark Poulson, Robbie Smith, Russell Smith, Dave Tafoya, and especially Bill Laskar. Myra O'Canna, Sandia Archives Coordinator, provided the

majority of the photographs, including those donated to the Archives by Glenn Fowler and Leon Smith. Rodema Ashby, Bob Bickes, Jim Chavez, Julie Clausen, Irene Dubicka, Herb Filusch, Gray Lowrey, Rita Pitts, Biu So, and Suzanne Stanton provided photographs that were not available elsewhere and we thank them. We would also like to thank Rod Geer, Iris Aboytes, and Nancy Campanozzi in Employee Communications and Media Relations for providing several crucial photographs.

For permission to reprint photographs not created by Sandia, we are grateful to: AT&T Archives (bottom photograph on page 50); Roger Meade of the Los Alamos National Laboratory Archives (photographs of Groves, Oppenheimer, and Larsen on page 14, and the photos on pages 16, 17, 18, 19, 21, the bottom of 22, 29, and the bottom of 70); the Massachusetts Institute of Technology (photograph of Jerrold Zacharias on page 14); J. J. Miller (airplane destruction photographs on page 25); and the Solar Electric Light Fund (photograph on page 323).

Our gratitude goes to Jan Gaunce, who designed the book and demonstrated infinite patience with our many changes and opinions about the format. We are grateful also to Dick Craner and Bruce Green of Sandia's Classification Office for reviewing and re-reviewing the text to ensure that no classified information was released, and to Craner for his insight and editorial assistance. Our thanks also go to Bob Park of Sandia's Legal Department for his timely review. And we would like to thank Roger Anders of the Department of Energy for providing comments on an early draft, and Linda Cusimano of Sandia's Recorded Information Management Department for reviewing the final draft. Finally, our appreciation to Anna Nusbaum, Manager of Recorded Information Management, for providing ongoing support and encouragement.

Carl Mora
John Taylor
Rebecca Ullrich

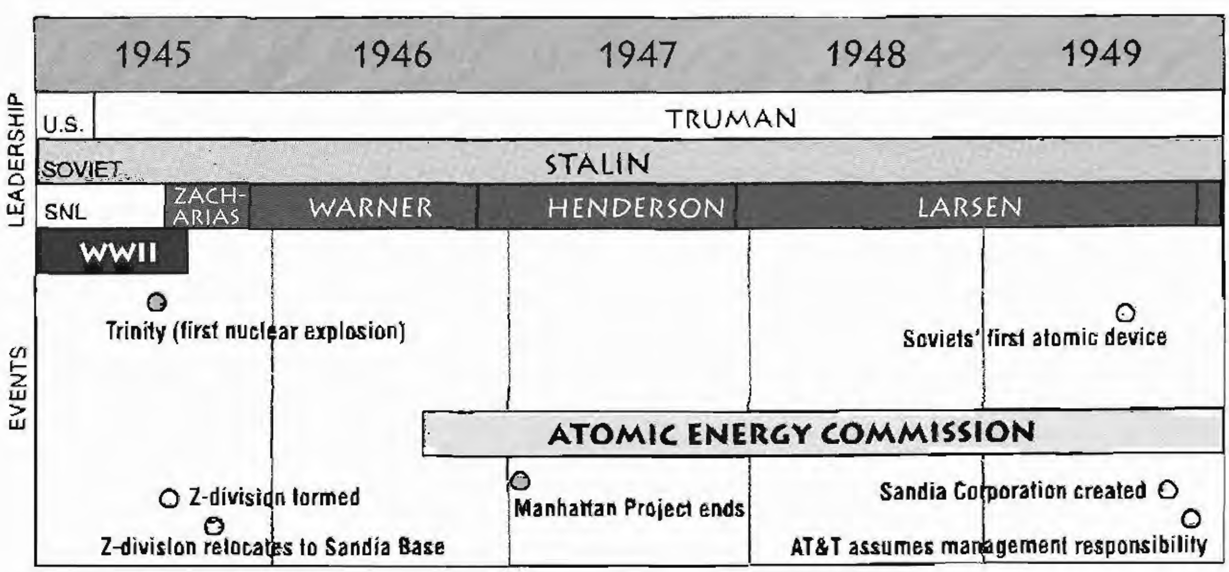
PROLOGUE

It is hereby declared to be the policy of the people of the United States that, subject at all times to the paramount objective of assuring the common defense and security, the development and utilization of atomic energy shall, so far as practicable, be directed toward improving the public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace.

Atomic Energy Act of 1946

The Atomic Energy Act of 1946 claimed a broad mission for the stewards of atomic energy in America. The Act's demands created an equally broad complex of agencies, laboratories, and production facilities to explore and support this mission. Focused on the paramount objective of national security, this complex was, for the first fifty years of its existence, devoted to the design, development, production, stockpiling, and safeguarding of nuclear weapons. The complex itself was made up of a series of individual facilities, with distinct purposes and different relationships to the government. Each was shaped by the political and cultural milieu of post-World War II American society. In particular, although most were born in America's World War II atomic bomb project, they were reared in the era we know as the Cold War.

The Cold War is over now and the historical evaluation of the era and its institutions has begun, even as those institutions and their employees begin to

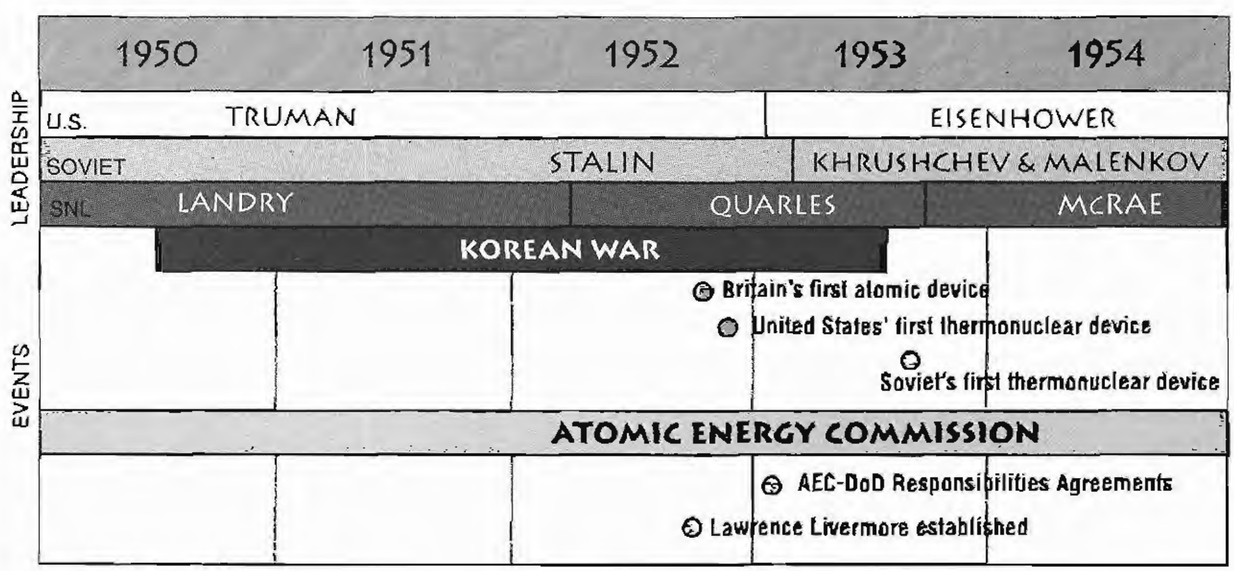


mold themselves to a new era and its culture. But the Cold War was not a single event, monolithic in its presence and influence. Several individual elements in this interplay between the superpowers shaped the pace and purpose of the activities within the defense complex as a whole.

The book that follows lays out the work of Sandia National Laboratories in its first fifty years and the events and decisions behind that work. But all of those decisions reside in the context of international events and shifting national priorities. As a result, within the broad chronological sweep of Sandia's half century are several turning points that caused the Labs to shift its emphasis and explore new areas. The result has been an ongoing evolution in the nature and focus of the projects Sandia has undertaken, all within the context of serving the national interest by preserving national security.

The Atomic Energy Act placed the control of atomic energy in civilian, rather than military hands, creating three groups to manage the process. The Atomic Energy Commission (AEC) was given a virtual monopoly over atomic energy in America. To ensure that military needs were met regarding atomic weapons, the AEC had a liaison committee of military officials, creating "dual-agency" responsibility for the weapons and their use. The Act also created the Congressional Joint Committee on Atomic Energy (JCAE) to act as legislative overseer of the AEC. The JCAE was a standing joint committee composed of equal numbers of members from both political parties. Throughout its tenure, the JCAE, its members, and its decisions served as powerful forces shaping the context and the content of U.S. policy on atomic energy in general and nuclear weapons in particular. Finally, the Act created the General Advisory Committee, composed of prominent scientists and engineers serving as advisors to the AEC.

Within this administrative arrangement the existing World War II institutions for atomic research and weapon production were further defined and joined by a broad array of additional facilities. By the early 1950s, the general structure of what we came to know as the nuclear weapons complex was in place. Beyond the top administrative agencies, most of the operation of sites and facilities was done by civilian contractors, a

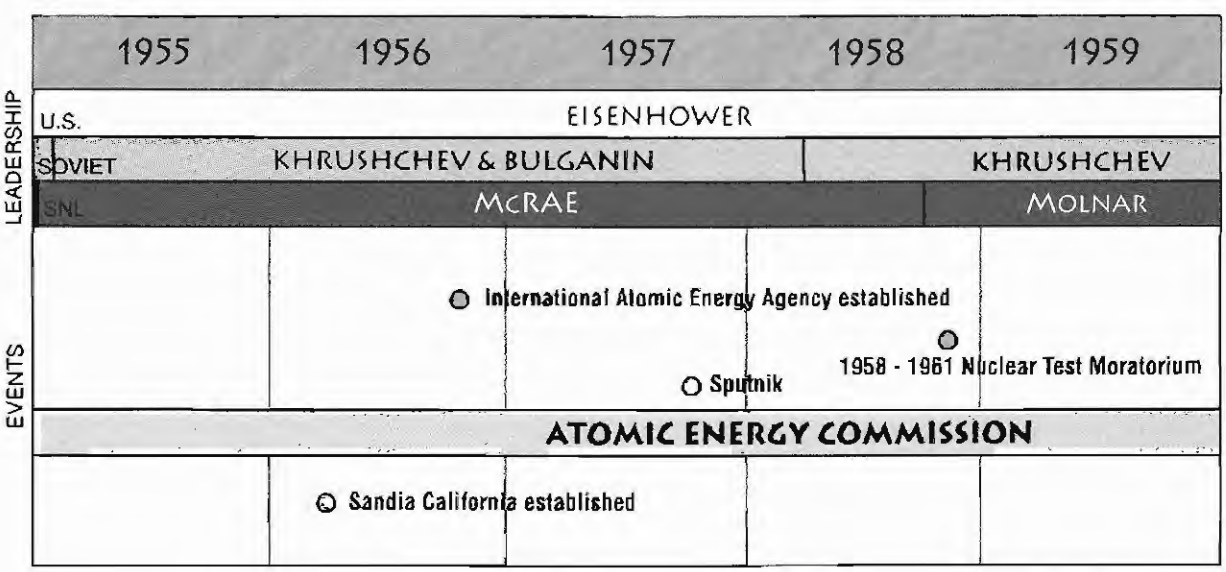


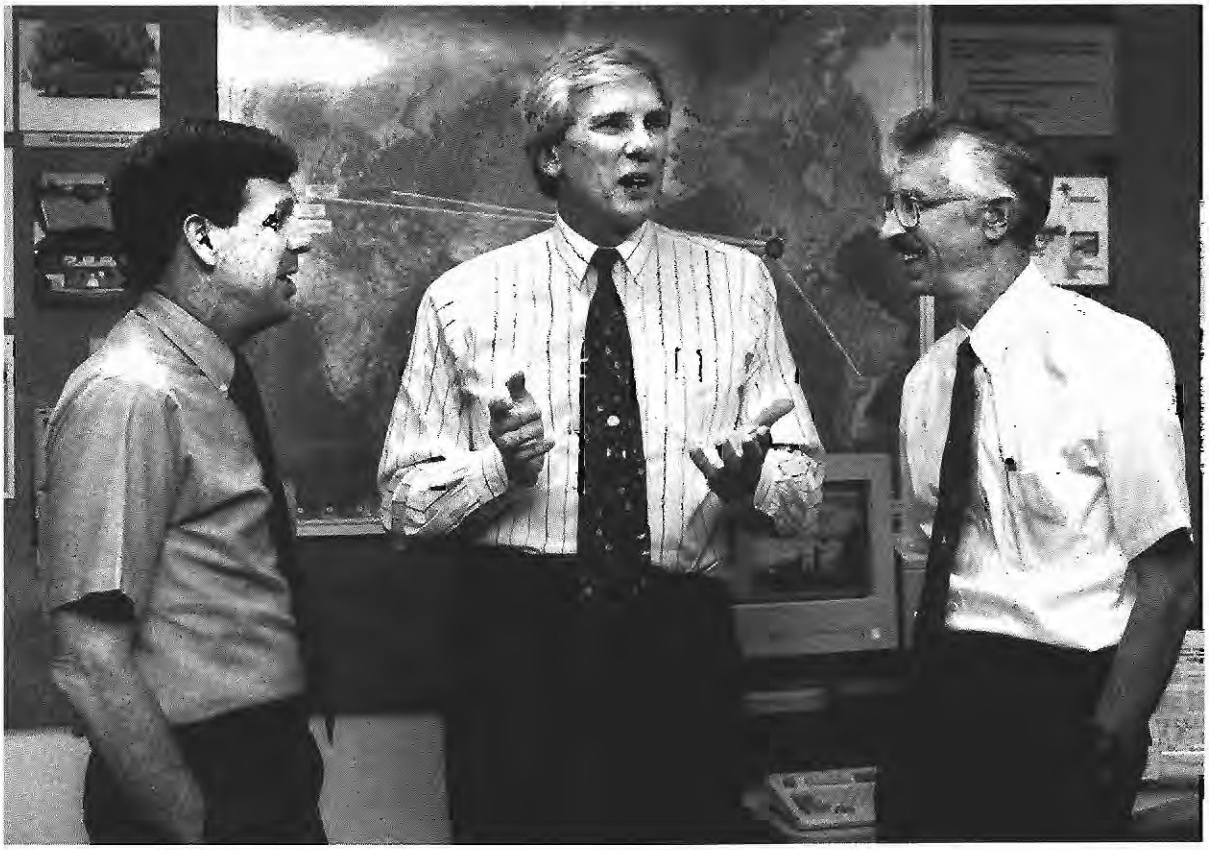
direct outgrowth of the large defense industry of World War II. The AEC maintained contact and policy implementation with its contractors through field offices.

The apparent triumphs of the huge and expensive wartime research and development effort spent on projects like radar, the proximity fuze, and the atomic bomb gave rise to a belief that scientific and technological resources should be nurtured and maintained by the federal government, ready to provide service in an emergency. The system of national laboratories that has grown in the post-war era is based firmly on this belief. The laboratories are unlike most other research and development facilities in the nation. They are fully owned by the federal government, but they are managed by contractors. The management contracts — known as GOCOs (government owned, contractor operated) — varied for each facility and have changed over time as different operators have been involved.

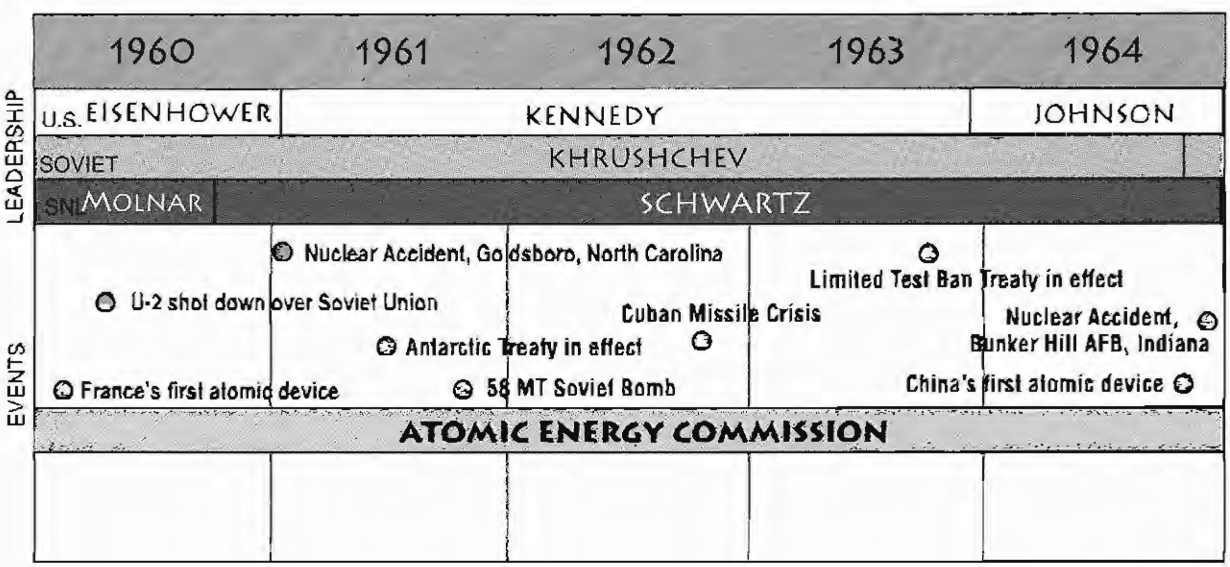
In addition to the administrative agencies and the laboratories scattered across the nation, an integrated complex of contractor-operated nuclear materials production facilities, component production plants, and weapon assembly plants has produced the nation's nuclear weapon stockpile. The three laboratories involved in nuclear weapons design are Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Sandia National Laboratories. Los Alamos and Lawrence Livermore design the high explosive/nuclear system package, while Sandia designs the rest of the nuclear bomb or warhead, including the arming, fuzing, and firing systems along with other essential components. In essence, Sandia "weaponizes" the nuclear systems designed at its partner laboratories. Sandia also serves as the liaison with the integrated contractor complex to see the production phase of the work through to completion. Although this function is currently diminishing as the production complex downsizes, Sandia is still the principal point of contact with DoD and the military services.

Sandia emerged from World War II's Manhattan Project. During the war, the design, development, testing, and assembly of Little Boy and Fat Man (the two atomic weapons used during the war) were all done at Los Alamos, high on a hill in north central New Mexico. In late 1945, the Los Alamos





1996 DOE nuclear weapon laboratories directors meet. *Left to right:* Bruce Tarter of Lawrence Livermore, Paul Robinson of Sandia, and Sig Hecker of Los Alamos.

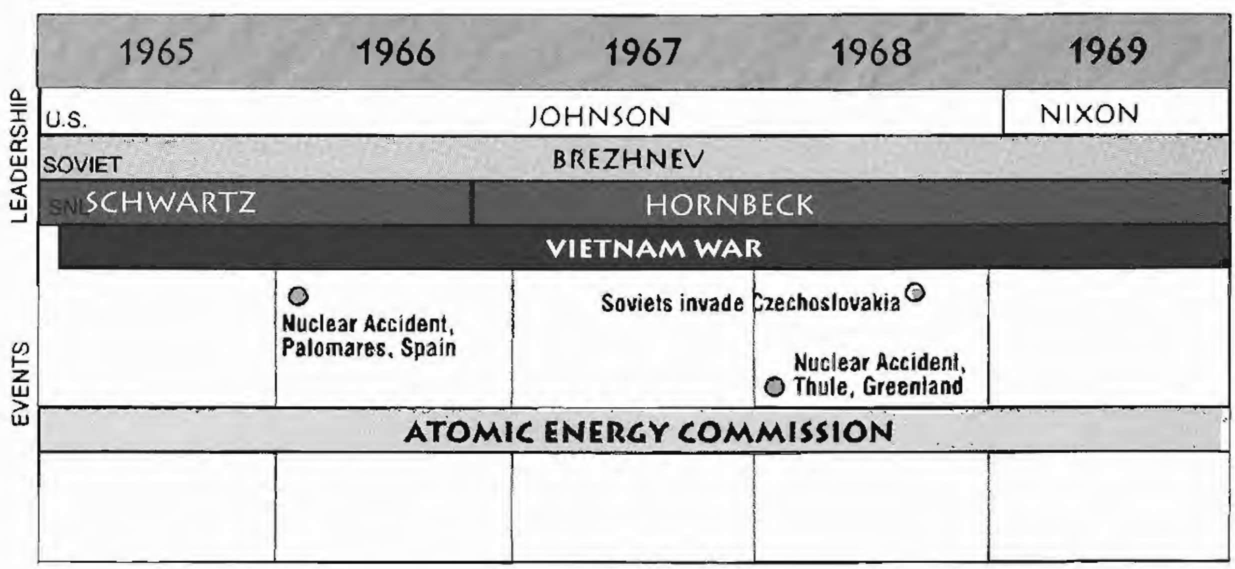


Laboratory began transferring its field testing and engineering organization, known as Z-division, to Sandia Base near Albuquerque. Staff from the Army Air Corps 509th Composite Group at Wendover Air Base in Utah joined the original group to do weapon assembly. This organization formed the nucleus of Sandia Laboratory, created in 1948 as a separate branch of Los Alamos. The following year, the laboratory formally separated from Los Alamos when the University of California, Los Alamos's managing contractor, asked to be relieved of the responsibility. American Telephone and Telegraph (AT&T), at the request of President Truman, agreed to take over management of the facility and Sandia Corporation, a wholly owned subsidiary of Western Electric, AT&T's production arm, was formed to serve as the managing contractor.

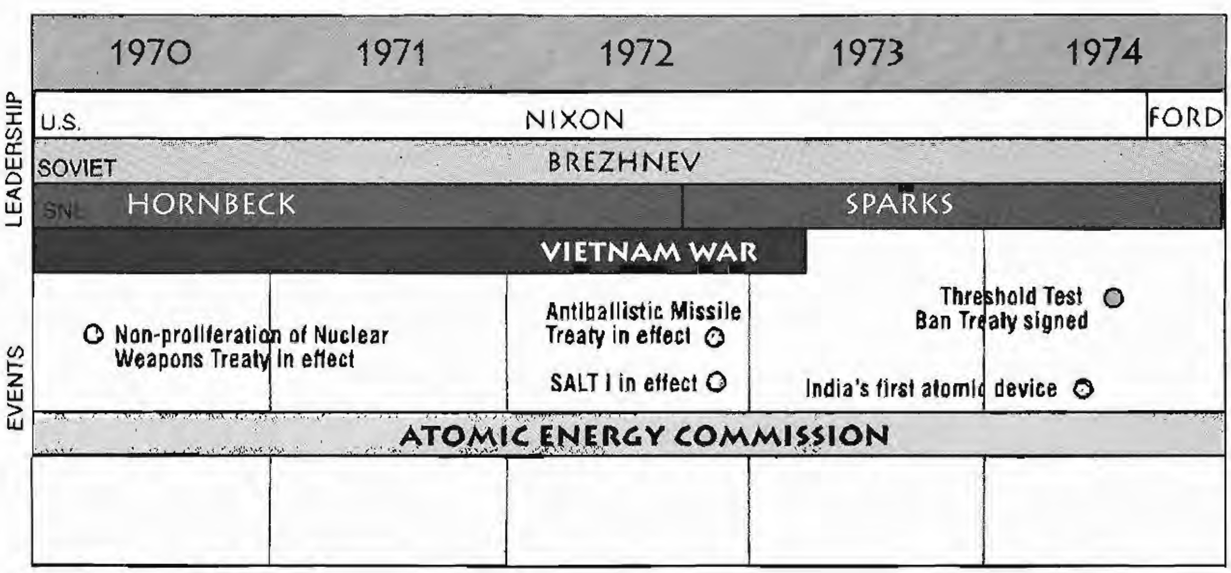
In the late 1940s, the nuclear stockpile was small, consisting of a few hand-crafted devices modeled on the Fat Man design used in World War II. At that time, America had a monopoly on nuclear weapons, but as tensions between the U.S. and the Soviet Union grew and hardened there was an increasing sense that others would have a nuclear weapon capability soon. The focus within Z-division was on nuclear weapon ordnance engineering and production coordination, with a growing emphasis on research and development to improve weapon designs.

In 1949, as the Soviet Union successfully tested its first atomic device, a national vision emerged of a larger stockpile, mass-produced and quickly available. Sandia's responsibility for coordinating weapon production among the various AEC contractors expanded even as the number of weapons in development grew. The onset of the Korean War stimulated several emergency development programs to ensure that new types of weapons were available.

America tested its first hydrogen bomb in 1952, with the Soviets following closely in the next year. That same year, a new nuclear weapon design laboratory was formed in Livermore, California as a competitor to Los Alamos in response to this perceived Soviet threat. The arms race between the two powers pressed the pace of weapon development for the next decade and a half, with the stockpiles of the two nations growing rapidly in both variety and number of weapons.



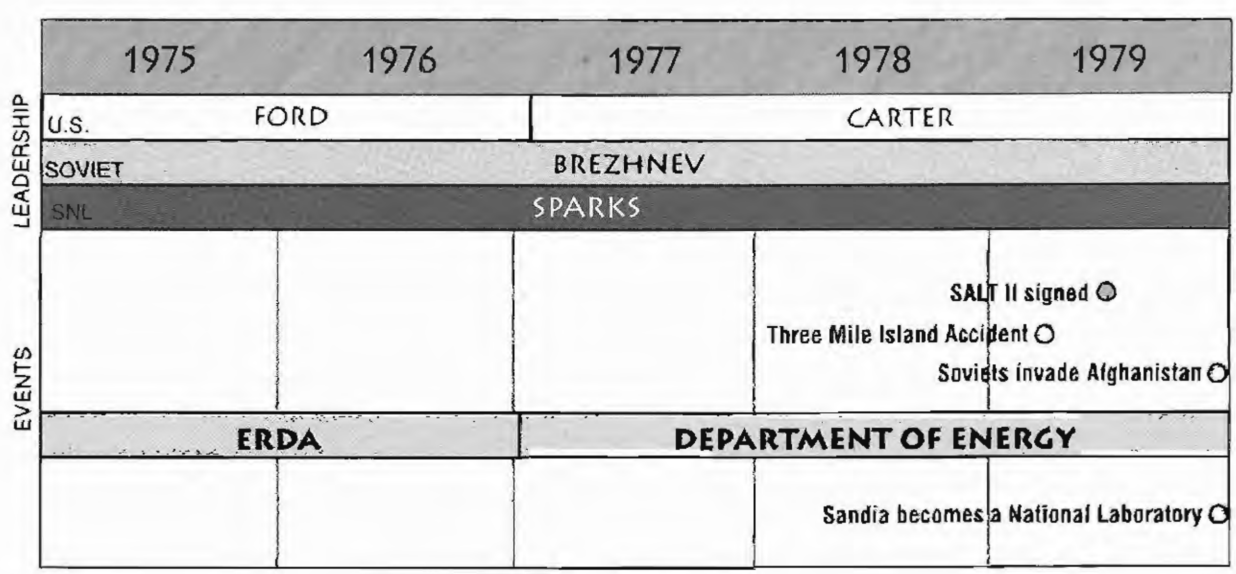
Main technical area of Sandia National Laboratories, Albuquerque, New Mexico in 1994.



By 1952, the weapon production complex was in place and Sandia focused on weapon development, expanding its engineering staff to accommodate the expanding number of weapon projects underway. In addition to design and production coordination, Sandia also undertook extensive field testing of components and supported the atmospheric tests sponsored by its partner laboratories. Nuclear testing halted temporarily in 1958 when the U.S. and the USSR agreed to a test moratorium, but began again in 1961 when the Soviet Union resumed testing. Sandia experienced rapid shifts of engineering staff to accommodate these changes. Further flexibility was required in response to concerns about the custody of nuclear weapons deployed to Europe for North Atlantic Treaty Organization (NATO). Sandia developed and offered the Permissive Action Link (PAL) to ensure American control over the use of the weapons. In addition, in 1960, the JCAE granted Sandia the flexibility of level-of-effort funding — funding the laboratory at a stable level and allowing its internal management to decide where the technical effort was to be expended. This meant that employees and resources could be moved quickly from one project to another as the need arose and facilitated a responsive, "can-do" attitude for Sandia.

Recognizing that such flexibility was crucial in responding to rapidly changing national defense demands, Sandia also established an advanced development group to anticipate future projects. Simultaneously, the Labs took its first steps into areas other than nuclear weapon development, becoming involved in work on technologies to monitor nuclear testing in response to the test moratorium and the Limited Test Ban Treaty of 1963, working with National Aeronautics and Space Administration (NASA) to enhance the safety of aerospace nuclear power systems, and applying some of its techniques to the development of conventional weapons and intrusion sensors for use in the Vietnam War.

In the 1960s and early 1970s, the growing emphasis on research to strengthen the underpinnings of the engineering effort resulted in a concerted effort to hire more scientists and engineers to bolster and expand Sandia's research efforts. Sandians were also expanding the types of projects they worked on. National and international events, including the energy crisis and the terrorist acts at the Munich Olympics of the early



1970s, caused Sandia to become involved in new areas of energy research and in physical security and safeguards for facilities.

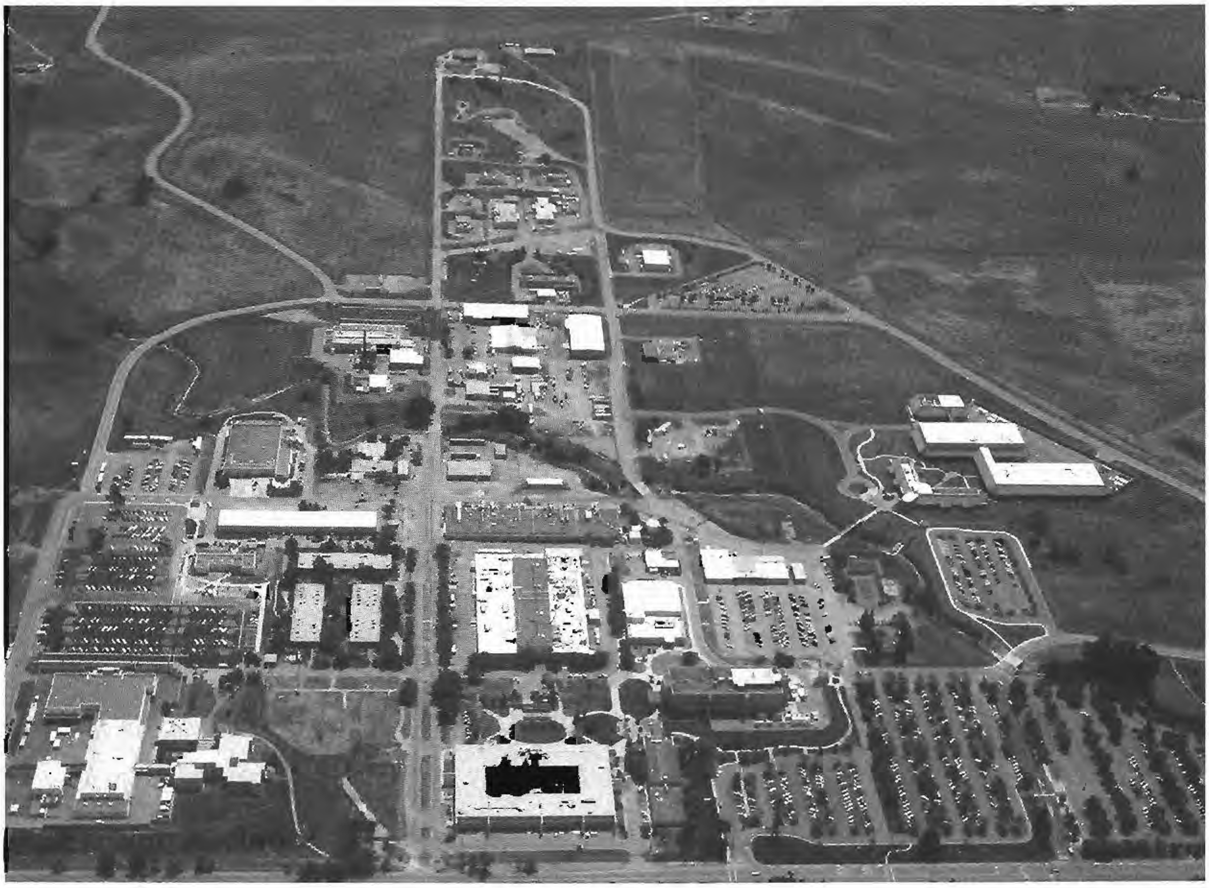
Throughout this advance into new areas Sandia had maintained its responsibilities in developing new weapons as well as maintaining the safety and reliability of the existing stockpile. As international arms control efforts increased in the late 1970s and throughout the 1980s, more emphasis was placed on treaty monitoring, while improvements were made in methods of ensuring the safety, security, and use control of the national stockpile.

With the end of the Cold War in the late 1980s and the decision to stop developing new weapons in the early 1990s, Sandia's role as stockpile steward has taken on a new importance. The existing stockpile requires constant attention to ensure its continued safety, security, reliability, and applicability. In addition, the emphasis on nonproliferation has taken on an even greater urgency as the nuclear powers dismantle part of their stockpiles and other nations look for opportunities to develop nuclear capabilities. Sandia has made a concerted effort to take its knowledge of nuclear weapons and apply it to international nonproliferation efforts.

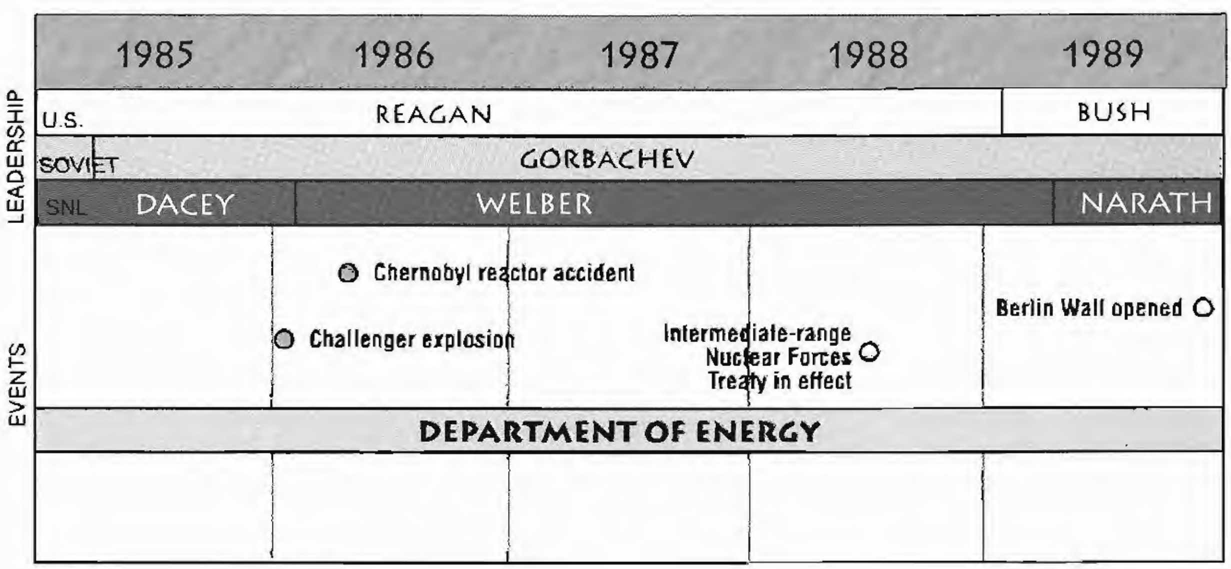
The structure of the system that emerged from the Atomic Energy Act proved durable. Although the AEC and the JCAE were dissolved in 1974 and 1976, respectively, their work continued under the auspices of the Energy Research and Development Agency (ERDA) and then the Department of Energy (DOE). The nature of this complex — decentralized, but integrated — has proven flexible enough to absorb the changing emphasis within the general goal of preserving national security.

The details of how Sandia went about fulfilling its mission and responding to national and international events are related in the following chapters. As Sandia's story unfolds, four essential themes will become apparent. First, as an engineering laboratory, Sandia has developed a distinct culture over the years. With a practical emphasis on getting the work done and the product out, the Labs' employees have always prided themselves on a can-do ethos — a willingness to take on new tasks, to work long hours, to focus on details, to reward innovation. Reflecting the technological

		1980	1981	1982	1983	1984
LEADERSHIP	U.S.	CARTER	REAGAN			
	SOVIET	BREZHNEV			ANDROPOV	CHERNENKO
	SNL	SPARKS	DACEY			
EVENTS						
		DEPARTMENT OF ENERGY				



Sandia National Laboratories Livermore, California site in 1995.

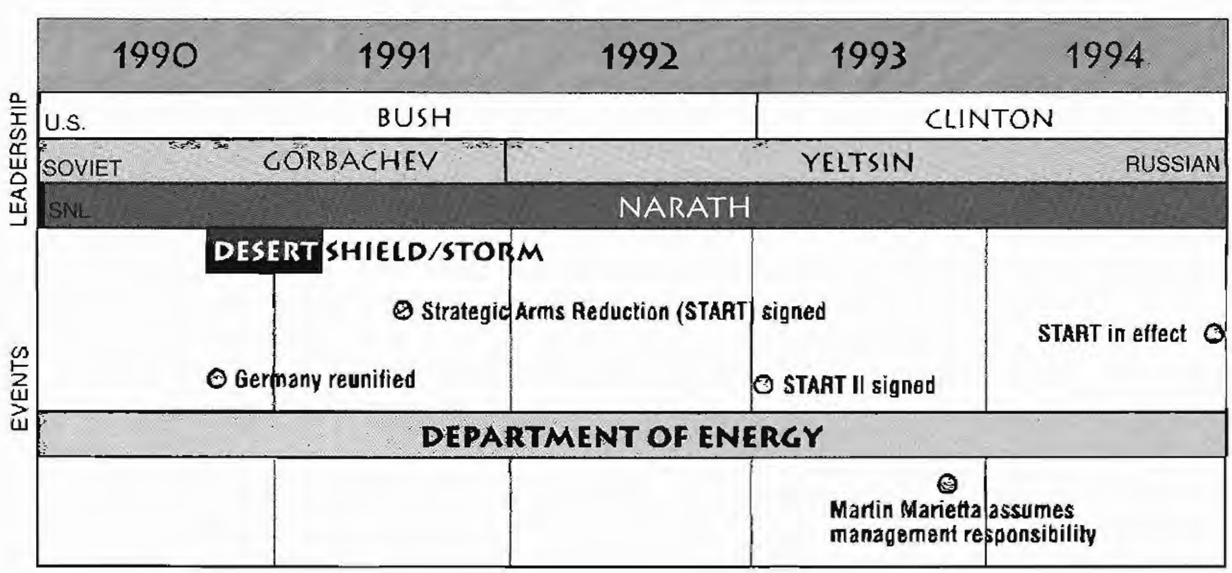


enthusiasm identifiable in American science and engineering more broadly, this attitude thrived on the technological challenges inherent in the arms race of the Cold War and, more recently, in the move to a post-Cold War world. The result has been a remarkably stable workforce. The last of the employees who came to Sandia from the Manhattan Project or were hired right after World War II have retired, but only recently. Thirty- and forty-year careers have not been unusual at Sandia. This level of loyalty to a single employer grew largely out of the challenges in the work, as well as an abiding faith in its importance.

Second, Sandia has long realized that because of the tremendous destructive potential of nuclear weapons there must be extremely small allowable risks of failure in their safety, security, and use control. Over the years, the insistence on weapons that will work reliably has been joined by an adamant demand that they not work when they are not supposed to — that is, when they are involved in accidents or fall into unauthorized hands. These two demands ultimately press in different directions; after all, the safest weapon would be one that could never work. This tension led Sandians to offer and promote technological solutions to problems of safety, security, and use control, often leading the way on these issues within the weapon community.

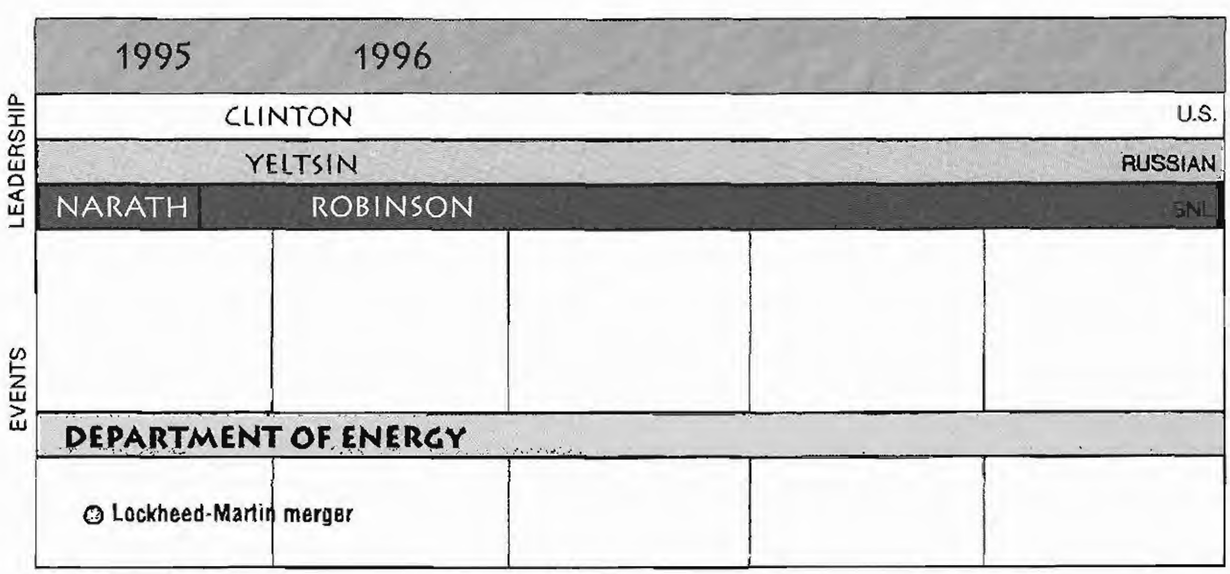
The third theme that emerges from Sandia's history has already been mentioned — the flexibility in structure and funding that allowed for extensive and quick mobilization of its research and development capabilities. Sandia has had both the breadth and depth of expertise to support its mission programs. Due to its essentially independent internal technical capabilities and management style, it also has had the flexibility to allow a project to draw on relevant capabilities from across its facilities and among its personnel.

Finally, a fourth theme appears as a result of the previous three: Sandia is a national laboratory. It, its partner laboratories, and the national laboratory system at large, were designed to serve the national interest in an innovative and independent manner. This is not a facility expected to do only what it is told to do. It is, rather, an institution that has not only been responsive to the requests levied by its national security customer base, but also has been counted upon to look forward, identify,



and offer creative solutions to problems that no one else recognized.

This, then, is the story you will find in the following pages: a single national laboratory maintaining a distinct style and mission while serving as one of the integral components of a vast but closely woven network of federal administration, national laboratories, and integrated contractor complex. For Sandians this has been an opportunity to work on important national security problems in a challenging and constantly changing environment.



This July 11, 1945, aerial view toward the east indicates the isolation of Sandia at the time. In the center foreground is Kirtland airfield and in the background is Sandia (Oxnard airfield).

I

FROM Z TO A CORPORATION

You have here an opportunity to render an exceptional service in the national interest.

Harry Truman

How should nuclear weapons be managed? This question challenged leaders of the Manhattan Project and of Z-division of Los Alamos Laboratory at Sandia Base in 1945, as it would the nation throughout the rest of the 20th century. Answers to this question were as varied as the number of agencies and people involved. Some thought nuclear weapons unique and deserving of strong civilian control; others considered them merely powerful conventional weapons that should be in military custody. Army engineers of the Manhattan Engineer District thought they should remain in charge of weapon development, while the Navy and Air Force sought roles in the program, and civilian scientists opted for university management. Fundamental answers to the question were forged during the tumultuous postwar years as the United States put World War II behind it and entered a longer Cold War.

Shifting political responses to the fundamental question of how to manage nuclear weapons generated turmoil throughout the formative years of the nuclear ordnance laboratory at Sandia. First, it was commanded by the Manhattan Engineer District and then managed by the University of California. Finally, after many alternatives were considered and rejected, "Ma Bell," the American Telephone and Telegraph Company (AT&T), assumed responsibility for the contract with the civilian Atomic Energy Commission (AEC). These transitions resulted in a management pattern that prevailed throughout the Cold War and endowed Sandia with a corporate culture of enduring value.

MILITARY MANAGEMENT

General Leslie Groves and Colonel Kenneth Nichols, leaders of the wartime Manhattan Project, selected the future site of Sandia National Laboratories in 1945 after Groves and J. Robert Oppenheimer agreed that engineering for nuclear weapons should be transferred from Los Alamos. Los Alamos suffered from shortages of housing and utility services, and transporting materials and equipment to and from the airfield in Albuquerque or the rail depot in Lamy was slow and costly.

During June 1945, the Manhattan District sent Lieutenant Colonel Robert Lockridge and officers from detachments at Los Alamos and Wendover airfield in Utah to examine potential sites for a field testing and weapon assembly operation. These officers surveyed Kirtland Field, an army staging and training facility near Albuquerque. Kirtland, formerly Albuquerque Army Air Base, was renamed in 1942 in honor of military aviation pioneer Colonel Roy C. Kirtland. Kirtland Field was much closer to Los Alamos than the headquarters of the 509th Composite Group at Wendover, Utah or other airfields used for bomb ballistics testing. Isolated on a mesa east of the Rio Grande, Kirtland was also several miles from Albuquerque, the nearest town.

Then home to 65,000 people, Albuquerque served as a railroad shipping center for ranchers and farmers. Travelers on the Santa Fe Railway or TransWorld Airlines knew the town

General Leslie Groves, Manhattan Project Commander, made the 1945 decision to move the ordnance engineering Z-division from Los Alamos to Sandia Base at Albuquerque.

J. Robert Oppenheimer, wartime director of Los Alamos Laboratory, supported the 1945 decision to transfer nuclear ordnance engineers to Sandia.

Paul Larsen came from the Johns Hopkins University Applied Physics Laboratory proximity-fuze project in 1947 to lead Z-division during its conversion into Sandia Laboratory.

Jerrold Zacharias led the Z-division transfer from Los Alamos to Albuquerque in 1945. Here, he pours a chemical into a molecular beam experiment.

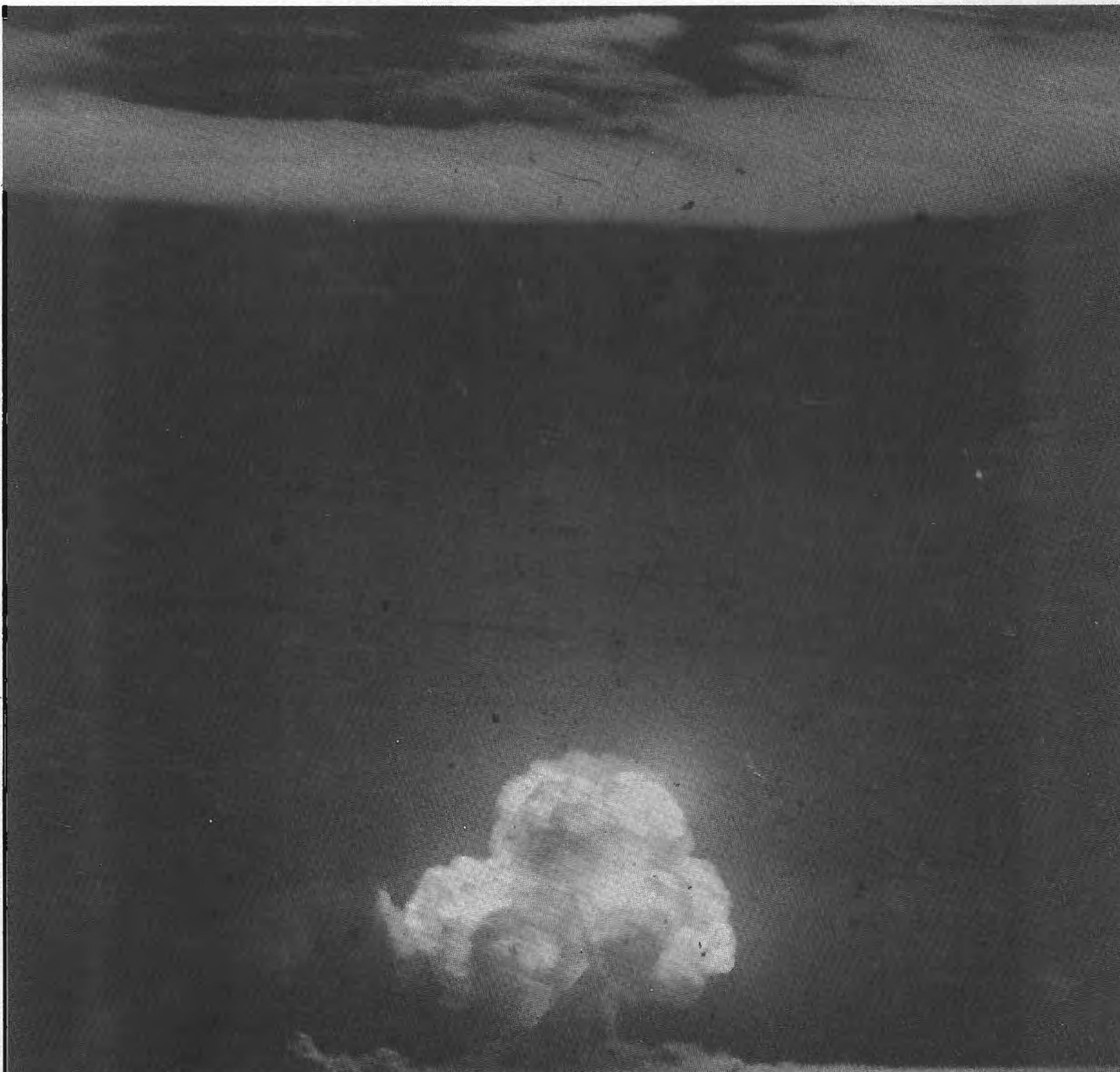
only as an interesting stop on the way to or from the west coast. East of the airfield stood a cluster of ramshackle buildings, some remaining from the old municipal Oxnard airfield and others brought in by the Army Air Corps after it acquired the site in 1942 to train aircraft mechanics. Known as Sandia Base because it was near the Sandia Mountains, the site had served as a convalescent center for wounded airmen in 1944; and by 1945 it had become a dismantlement center for surplus military aircraft.

A short distance south of Sandia Base, toward Coyote Canyon, a secret Navy-sponsored project led by E. J. Workman was winding down in 1945. Workman, a physics professor at the University of New Mexico, had joined the Applied Physics Laboratory in Maryland for research on the proximity fuze. With a contract to conduct testing for the proximity fuze project, he returned to New Mexico, suspended model aircraft from cables between two towers, and fired proximity-fuzed shells at them. This testing was successful. During 1945, proximity-fuzed shells proved so effective against German V-1 buzzbombs and Japanese kamikazes that development of the fuze has been ranked with radar and nuclear weapons as one of the vital technological breakthroughs of World War II.

Sandia Base seemed a logical choice for the Manhattan Project's ordnance assembly and testing center. During the summer of 1945, officers and enlisted men from Army detachments at Los Alamos and Wendover airfield transferred to Sandia Base, bringing with them non-nuclear weapon parts that had not been sent to the Pacific. Shipments of parts for atomic bombs ordered before war's end were also rerouted to Sandia Base, where they were stored in crates in the open for lack of warehouses. The Army moved prefabricated buildings to Sandia Base, began construction of three new buildings and a Quonset hut, fenced the area, and provided a security system that included tanks, towers, and even canine patrols to protect the embryonic national stockpile of nuclear weapon parts.

During the war, the Manhattan Project had established a widely dispersed weapon production complex. Oak Ridge produced the enriched uranium used in the gun-type Little Boy bomb, and Hanford created the plutonium used in the implosion-type Fat

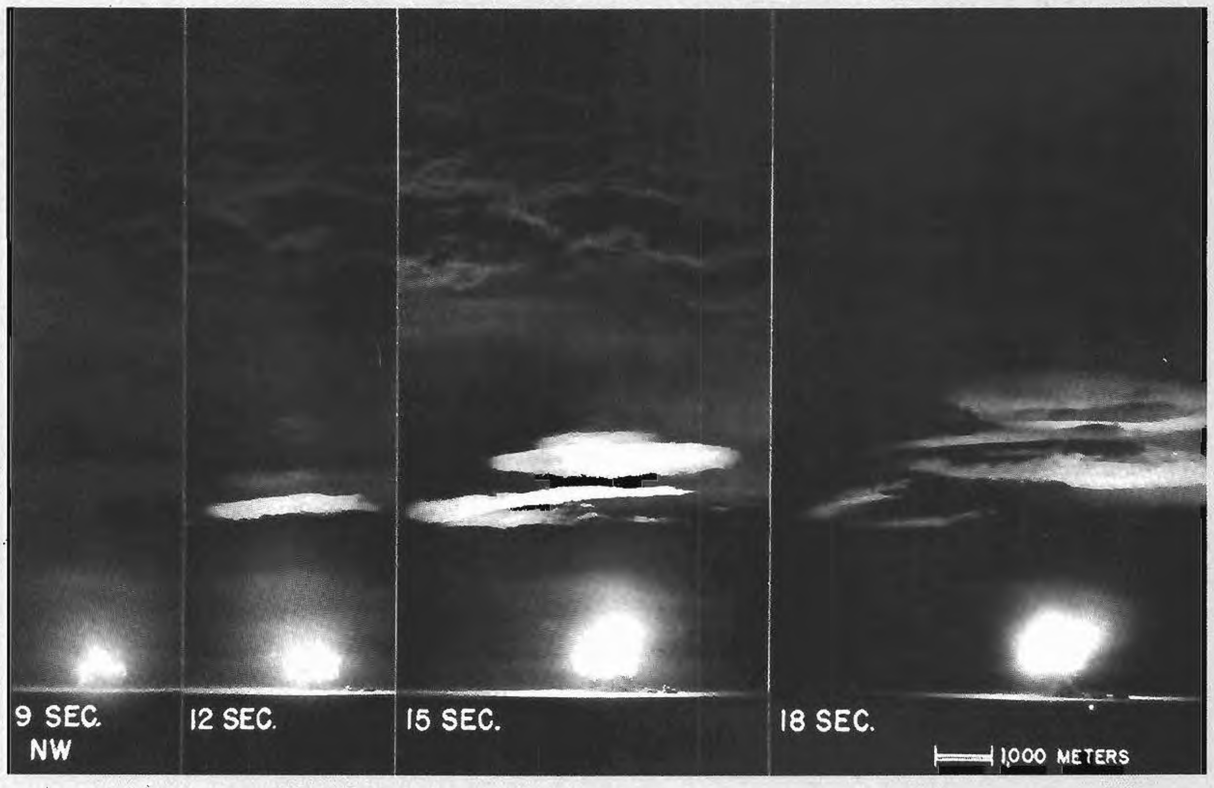
E. J. Workman's proximity-fuze testing contributed to Allied victory in World War II. In an area now part of Sandia, artillery shells with proximity fuzes were fired at mockup aircraft suspended between the towers visible next to the Manzano foothills in this photograph.



At Trinity

Since Sandia grew directly out of World War II's Manhattan Project, several of the Labs' early employees had worked on the Fat Man or Little Boy designs and a few were present to witness the Trinity Test. They, and others, have provided a variety of eloquent accounts of the awe and fear inspired by the world's first nuclear detonation. Among these must be counted the description by Robert Henderson, a significant figure in the history of the atomic bomb's creation and post-war evolution.

By the time he retired as Sandia's executive vice president in 1974, Robert W. "Bob" Henderson was known as "Mr. Sandia," serving essentially as Sandia's senior engineer from 1947. Before the war, Henderson received an Academy Award for his special effects work at Paramount Pictures, where Ernest Lawrence recruited him in 1942 to work on development of the electromagnetic process used at Oak Ridge to separate uranium-235 for use in nuclear weapons. At the request of Robert Oppenheimer, Henderson transferred to Los Alamos where, among other services, he



This sequence of photographs shows the Trinity fireball beginning to form as clouds gather in the sky above the explosion.

helped select the site for the Trinity test of July 16, 1945. Two months after the test, he penned a personal account of his experience for a friend, from which come these extracts:

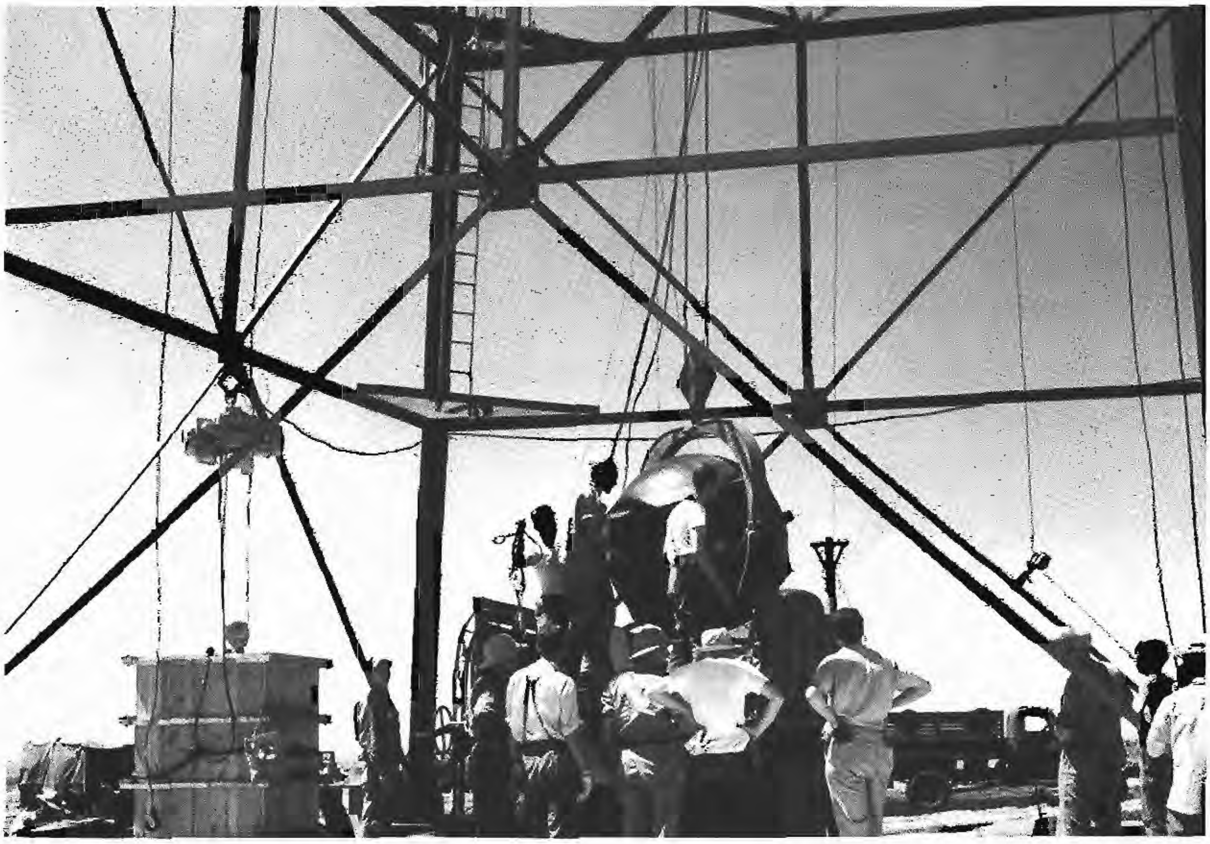
On the night of July 15 all was in readiness. The assembly of the bomb was complete and it reposed in its eerie solitude on the top of a 100′ steel tower shielded from the elements in a small corrugated iron shelter.

At 3 a.m. the morning of July 16th I drove in to the tower with the man who had the responsibility of closing the safety switches. Frankly if I had imagined in my own mind the terrific power..., I'm sure I would have been much more nervous than I was as I stood at the base of the tower in the drizzling rain looking up at the top, which was periodically illuminated by lightning flashes.

After my companion had satisfied himself that everything was as it should be, we drove back out of the area to our designated observation point 20 miles from the tower across the flat waste lands. We then rolled up in G.I. blankets and munched on hastily prepared sandwiches — altogether too excited to catch 40 winks.

Soon the time signals began coming in over the radio. When minus 1 minute was called out, I lay flat on the ground with my head propped on my elbows and the dark glass all ready to shove into place. At minus 5 seconds I caught the flash of a 5 lb. charge set off at the base of the tower and instantly slapped the dark glass in place. Then it came!

The whole heavens and ground lit up with a white light many times brighter than the sun — so intense that it came thru the welders glass like a 60 watt bulb.... Everything was white for an instant and then complete darkness. After an instant which seemed interminable my sight gradually returned and I dropped the dark glass to watch the explosion. Words cannot describe the seething ball of fire which was forming. The tower — 19 tons of steel — had been instantly vaporized. The ball of fire grew larger and larger and then started to rise. At this point we dropped to the ground again, put our fingers in our ears and started to yell to offset the blast when it hit us. It seemed ages for the sound to travel the 20 miles, but, oh boy! When it hit, it was a dilly. This was truly history in the making.



The operation to lift the Trinity device to the top of the tower. Art Machen, Bill Stewart, and Hert Lehr unload the shell of the device. Among the onlookers are, *far left,* Phil Dailey and Captain Wilbur Shaffer, and *fourth from left,* Norris Bradbury.

Man bomb. High explosives for implosion bombs were molded into lenses at a Navy station near Inyokern, California; mechanical and electrical bomb parts came from the Army's Rock Island Arsenal in Illinois; and other components came from industrial contractors. At Los Alamos, scientists and engineers assembled bombs as the parts arrived and fabricated inert devices for test drops at Wendover airfield in Utah and at Salton Sea and other California bases.

In July 1945, Los Alamos director Oppenheimer formed Z-division under Jerrold Zacharias to manage the engineering design, production, assembly, and field testing of the non-nuclear components associated with nuclear bombs. In September, the division's field-testing group, led by Dale Corson and Glenn Fowler, moved to Kirtland airfield to undertake continued testing, using a test range near Los Lunas, thirty miles from Albuquerque. When Zacharias left Z-division to return to academic life, Roger Warner and Norris Bradbury, the new director of Los Alamos, continued moving the engineers to Sandia for close liaison with the military services, thereby opening more space at Los Alamos. Not all Manhattan Project leaders approved of this transfer. While admitting that Sandia had been a logical choice during wartime, Commodore William Parsons preferred creating a peacetime engineering laboratory near Pasadena, California.

Norris Bradbury became director of Los Alamos Laboratory in 1945 when Robert Oppenheimer resigned.

Roger Warner directed Z-division in 1946. Here, he is at his shipboard command post during Operation Crossroads.

Progress in forming the ordnance laboratory at Sandia nearly came to a stop in early 1946 when Z-division personnel embarked for the Pacific to support the first postwar nuclear test series, Operation Crossroads. Further losses occurred when the officers and enlisted men at Sandia were discharged as the armed forces demobilized in 1946.

In addition to assessing nuclear weapon effects on military hardware, the 1946 Crossroads tests demonstrated a need for engineering and development. Because of bomb trajectory inaccuracies, the damage to the target vessels was lower than predicted; three years later the Air Force established its own Special Weapons Center and testing laboratory at Kirtland Field near Sandia. This laboratory was a forebear of the present-day Phillips Laboratory.

Members of the Z-division assembly group in the Pacific for Operation Crossroads. *Seated in front, from left:* Phil Dailey, Kenneth O. Roebuck, Arthur Machen, Ira "Tiny" Hamilton, Bryan Arthur. *Back row:* Roger S. Warner, Major Robert L. Roark, Colonel Jack Sutherland *seated,* Glenn Fowler *kneeling,* Alvin Van Vessem, William O. McCord, Gene Eyster *seated.*

Building 828 for mechanical assembly had a monorail and hoist to move weapons from the building to trucks. The steeple on the left is on the base chapel that was later moved off the base. Building 828 was still used in 1996.

In 1946, General Groves sent Colonel Gilbert Dorland to command Sandia Base and to organize a Special Engineering Battalion. Because of a severe housing shortage in Albuquerque, as in the rest of the nation, prefabricated housing consisting initially of 239 houses, 136 apartments, and 2 dormitories was brought in. Civilian Z-division personnel as well as the military were allowed to rent this housing and use military base facilities. By July 1946, all of Z-division except engineering design had completed its transfer to Sandia Base, comprising the entire surveillance, stockpiling, field test, and assembly groups for nuclear weapons.

"It is obviously desirable that this entire program be under the immediate control of our military organization," said Colonel Austin Betts of the War Department, U.S. Engineer Office, Santa Fe. He explained that the Manhattan Engineer District planned to separate Z-division from Los Alamos and University of California management, and to make it a civil service adjunct to the Special Engineer Battalion. That is, during the postwar years the Army planned to manage the nuclear weapon ordnance program much like one of its Engineer Districts or engineering laboratories — with military leadership supported by the federal civil service.

While the Army made its plans, Z-division regrouped. Its leader, Roger Warner, who with Arthur Machen had assembled Fat Man at Tinian in 1945, persuaded Machen to move to Sandia Base "to train the newly established special weapons unit in the occult art of atomic weaponeering and prepare a set of how-to-do-it manuals." Since his task included the assembly of high-explosive lenses, Machen hired explosives experts from the Hercules Powder Company in Tennessee for the job. They sometimes impressed visitors by pounding explosive castings with mallets to fit them together into the spherical shape required for implosion bombs.

Z-division took charge of the stockpile, collecting assorted bomb parts, assigning them identification numbers, and developing procedures for monitoring their location and condition. Donald Cotter, who later held a variety of important government positions, began his career at Sandia cleaning aircraft tail-warning radars for use as fuzes on early nuclear bombs. They were shipped from Air Force depots with sand in the boxes, and it was Cotter's job to remove the sand and refurbish them. "We used four of them in [each] bomb," he recalled, "because they were fairly unreliable."

Warner moved Sandia's bomb assembly operations into four new buildings, constructed under supervision of the Army post engineer. Z-division's assembly force first occupied Building 828, used for mechanical assembly. This building housed a machine shop and Sandia's first environmental testing machines — a cold chamber for assessing high-altitude temperature effects and a shake table to observe effects of severe vibrations. It had a monorail in its ceiling to hoist heavy bombs and move them onto trucks outside for transport to aircraft for testing. Systems development occurred in Building 838, the design and fabrication of telemetry instruments in 824, and the assembly of electrical parts in 839.

ATOMIC ENERGY COMMISSION BEGINS

Congress created the Atomic Energy Commission (AEC) in 1946 and President Truman appointed David Lilienthal its first chairman. When Roger Warner left Sandia to become the new agency's director of engineering later that year, Robert Henderson moved to Sandia from Los Alamos with Z-division's 147 engineers and technicians. During the war, Henderson had been recruited by Ernest Lawrence and Oppenheimer at the University of California, Berkeley, and later sent to Los Alamos as an engineer for implosion-bomb design. At Sandia, he acted as Z-division director until Norris Bradbury appointed a permanent director.

Congress and the President settled the issue of military versus civilian control of nuclear weapons through the Atomic Energy Act of 1946, which transferred nuclear research and development from the Army Corps of Engineers' Manhattan Engineer District to a five-member civilian Atomic Energy Commission (AEC). This decision terminated Army plans to convert Z-division

Manhattan Project leaders accepted the Army/Navy E Award for excellence at the end of World War II. *Left to right:* Robert Oppenheimer, General Leslie Groves, President Gordon Sproul of the University of California, Commodore William Parsons.

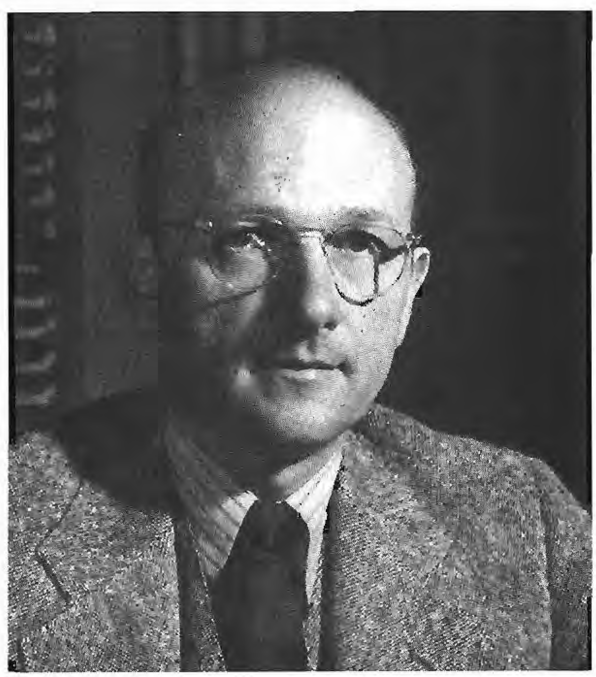
into a military command with civil service support. In early 1947, the AEC opened a Santa Fe Operations Office and established a Sandia field office at the Z-division facilities. The military area adjacent to the Z-division technical area was transferred to the Armed Forces Special Weapons Project, commanded initially by General Groves.

While close coordination with the Armed Forces Special Weapons Project and the military services remained vital to Sandia's success, after 1946 the oversight and funding of Sandia's activities emanated from the Sandia field office, which reported to the Santa Fe Operations Office and in turn to AEC headquarters. The Santa Fe Operations Office moved from Los Alamos to Albuquerque in 1951; in 1956 it was renamed the Albuquerque Operations Office, often referred to by the acronyms ALOO, ALO, or just AL. As required by the Atomic Energy Act, a high-ranking military officer headed the Division of Military Applications at AEC headquarters.

The Department of Defense (DoD), created in 1947, alerted the AEC to its weapon needs through the DoD-AEC Military Liaison Committee. This committee, mandated by a provision of the Atomic Energy Act, consisted of two senior officers from each of the armed services and, after 1948, was chaired by a civilian. Two Sandians served as Assistant to the Secretary of Defense for Atomic Energy, William "Jack" Howard during the 1960s and Don Cotter during the 1970s, and chaired the Military Liaison Committee. The committee and the military services were charged with drawing up specifications for the types of weapons that were needed and how they should perform. A document, called the Military Characteristics, set the specifications and design goals for Los Alamos, Sandia, and later for Lawrence Livermore.

After Congressional confirmation hearings in late 1946, David Lilienthal, formerly chairman of the Tennessee Valley Authority, became the first AEC chairman. After taking office, he and the other new commissioners embarked on an orientation tour of the facilities the AEC had inherited from the Manhattan District. Lilienthal was impressed by the eager young engineers and

Robert Henderson was acting director of Z-division in 1947. Known as "Mr. Sandia", he served essentially as Sandia's senior engineer from 1947 until his retirement in 1974.



David Lilienthal, first chairman of the Atomic Energy Commission, fostered industrial management for Sandia.

Army officers he met at Sandia Base. However, after he reported to President Truman that he could count the number of ready nuclear weapons on the fingers of one hand, an investigation into ways to multiply that number was launched.

As part of this investigation, John Manley of the AEC General Advisory Committee looked into the delays experienced at Sandia's Z-division. "One must realize," Manley reported, "that the wartime development yielded nothing more than a laboratory version of everything: weapons, test units, field kits, drawings, manuals. Any operation was very strongly dependent on technical knowledge of individuals; there was no time to write down more than an absolute minimum." Labeling Z-division a "shoestring operation," he attributed its survival under Army management to "the sense of national responsibility on the part of some individuals." Manley urged swift reorganization to standardize improved weapons, components, and test equipment; to prepare standardized drawings and manuals; to attend closely to production and procurement; to initiate adequate training programs; and to institute long-range development and testing. These, he reported, could only be accomplished by first alleviating personnel and facility shortages at Sandia Base.

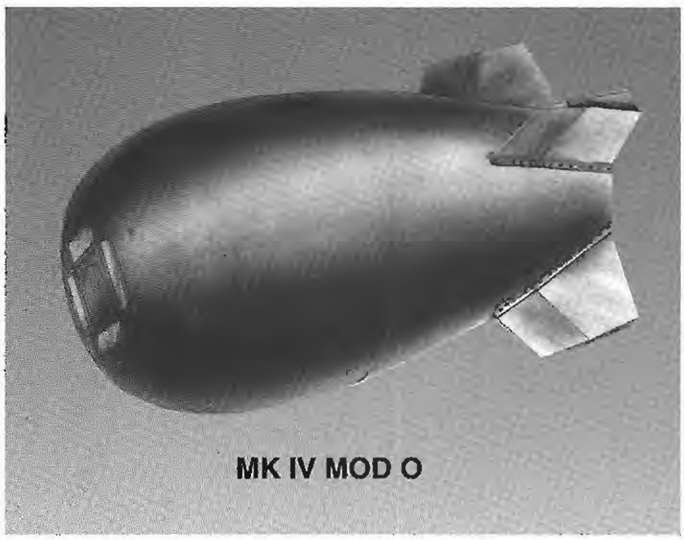
To undertake this reorganization, Paul Larsen was appointed Sandia's director in late 1947. Born in Denmark, Larsen started his career early in the century with the Marconi Wireless Company and went on to distinguish himself in the proximity fuze project during the war. Working for the Navy and the Applied Physics Laboratory of Johns Hopkins University, Larsen pressed development of the fuze from research to its production by the millions before the war's end. Richard Bice, then Sandia's director of engineering, said Larsen walked into a difficult situation at Sandia. "We came out of the R&D end of the game — to go into large-scale manufacturing, that was foreign to us," admitted Bice. "It grew rather slowly and people were somewhat upset in the higher levels with the speed to which it wasn't being done." Larsen's experience was highly relevant to the Sandia situation.

LARSEN'S ENTERPRISE

Aptly described as a man of enterprise, Larsen received full support from the fledgling AEC, which arranged with Los Alamos to elevate Z-division to laboratory status. Larsen thus became the director of Sandia Laboratory, a branch of Los Alamos still managed under the University of California contract with the AEC. Larsen initiated rapid expansion of Sandia's work force and facilities. A $25 million construction effort began in 1948 to build permanent structures to replace the mobilization-type, tar-paper and frame buildings erected by the Manhattan District. Larsen wanted the Army post engineer, Captain Luther Heilman, to manage this building program, but encountered difficulty getting Heilman discharged from the service. Larsen often surmounted such challenges by going directly to the top, and when General Omar Bradley toured Sandia, Larsen personally requested Heilman's transfer. Two days later, Heilman began a thirty-five year career at Sandia. The first permanent brick structure, Building 800, opened at Sandia's main entrance in 1949, and other substantial buildings of the Larsen program entered service in 1950.

Larsen and his personnel manager, Ray Powell, initiated vigorous recruiting, especially from the wartime proximity-fuze project. Some came to Sandia from the New Mexico School of Mines fuze-testing program, and Larsen persuaded the AEC to purchase the School of Mines buildings after the school moved to Socorro. Located off Gibson Boulevard two miles west of the Sandia technical area, the school buildings became the West Lab, home to Sandia's first contingent of scientists and managed by Robert Petersen, a former colleague of Larsen in proximity-fuze research.

For expedited weapon production, Larsen created a "Road" department headed by Frank Longyear. "Road," a code name perhaps emanating from the expression "get the show on the road," expanded from 20 to a total of 300 personnel within the year, increasing the rate of production to about two bombs a month. This rate seemed likely to provide the



The implosion-type Mark III and Mark IV nuclear bombs were huge, essentially hand-crafted devices based on the Fat Man design.

nation with all the nuclear weapons it needed, so long as it had a monopoly on those devices. In retrospect, the pace seems leisurely. If the President ordered the AEC to transfer a nuclear weapon to the military in some emergency, Larsen was allowed sixty minutes to get Sandians to the storage site and two hours to make the transfer.

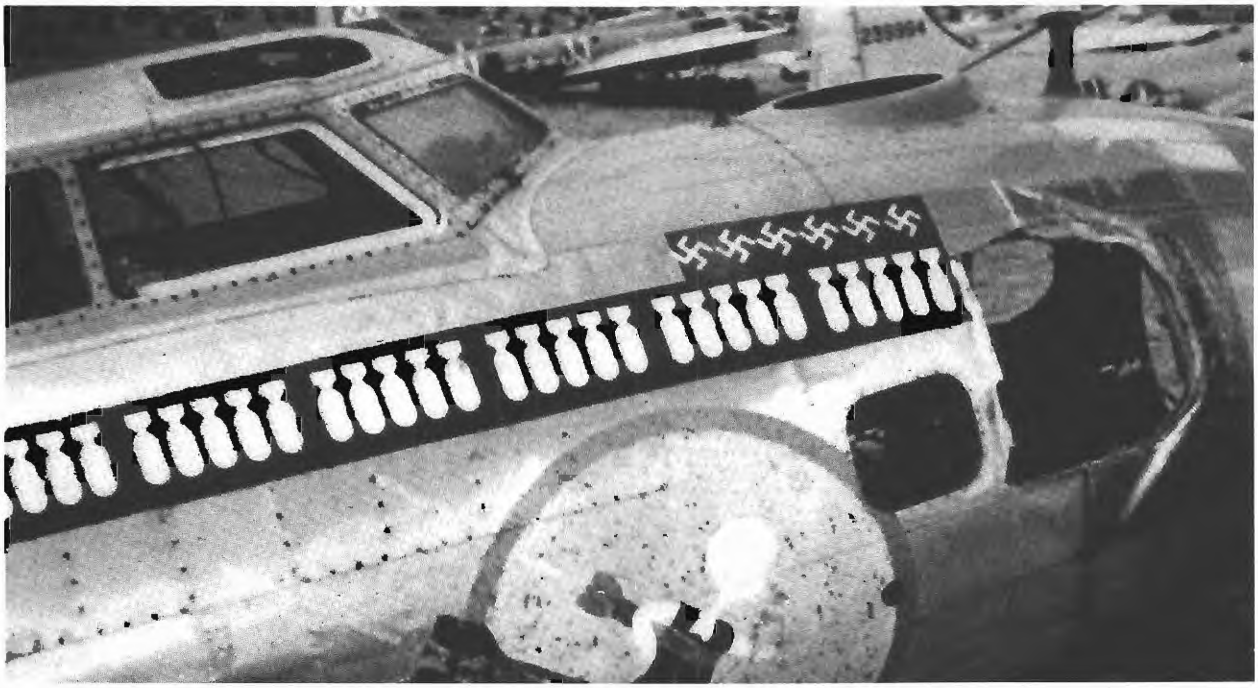
While building its engineering work force, Sandia emphasized a production orientation and insisted that recruits have at least a B average plus some pertinent experience. George Hildebrandt, who applied to Sandia with a master's degree in mechanical engineering, later recalled that his application was rejected several times because he was overqualified before he explained to his future supervisor how he had just rebuilt a Ford Model A. This "hands on" experience probably was more relevant than his master's degree for building the Mark III, Fat Man type weapon, that Los Alamos and Sandia had in production during the 1940s.

FIRST GENERATION WEAPONS: THE MARK III, MARK IV, AND MARK 6 BOMBS

The basic division of responsibility for development of the first generation of nuclear weapons was for Los Alamos to provide the high explosive and nuclear subsystem and for Sandia to provide all of the other parts necessary to produce a usable weapon. These "other parts" clearly differed from the Model A in George Hildebrandt's job interview. They represented state-of-the-art electrical and mechanical technology. During its first decade, Sandia not only designed and tested this technology, it also produced prototypes. For serial production, Sandia contracted in Albuquerque and elsewhere for most of the necessary parts.

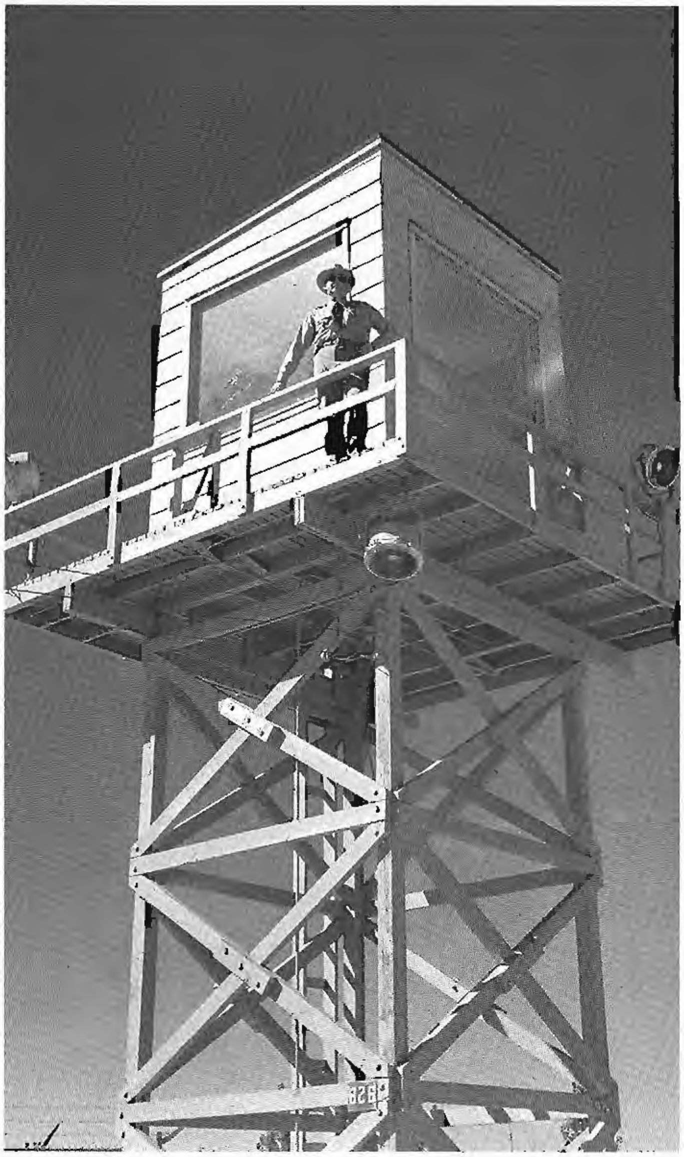
Sandia's first task was to design the case and non-nuclear components for the Mark III bomb, a weapon essentially identical to the original Fat Man. This weapon was so large that the largest aircraft of the 1940s could only carry one; yet, compared to modern weapons, it was a low-yield bomb requiring high-altitude delivery and burst height.

Internal batteries provided the power needed for fuzing the Mark III after it was released from the aircraft. These were lead-acid batteries that had to be charged for as long as forty-eight hours before use — a feature quite burdensome to the military services. The electrical power needed to fire the detonators came from the aircraft into a 700-pound firing set, known as the x-unit, which contained a huge capacitor to store the energy. Once the arming and fuzing sequence



Dismantlement of surplus warplanes was underway around Sandia until 1947. Among the aircraft to be salvaged was this veteran of many bombing missions in Europe. The swastikas indicate the number of enemy aircraft this bomber's crew was credited with downing, and the bombs indicate the number of missions flown.

A crane drops a heavy plate to slice up surplus aircraft for salvage at Sandia Base in 1946.



Cliff Hiner stands watch over the perimeter. Sandia's security force replaced military guards on patrol and on the guard towers until the towers were removed during the 1950s.

was complete, this energy was released as a high-voltage pulse to the detonators to fire the high-explosive lenses, thus compressing the fissionable material into a supercritical mass.

A spring-wound clock timer started when the weapon left the plane and operated for fifteen seconds to assure the bomber's escape before closing a circuit to enable a radar fuze. As a backup system to protect the aircraft and crew, the Mark III also had barometric switches, or baroswitches, to sense altitude from atmospheric pressure. At a preset altitude, the baroswitches closed contacts to start the radar fuzes. This barometric delay shortened the time radar fuzes would operate and helped prevent electronic jamming by enemy defenses.

The Mark III fuzing system used components from the Archie tail-warning radar system, used on aircraft in World War II to warn a pilot of an attack from the rear. In the Mark III application they sensed the distance to the ground and sent a firing signal to the x-unit at the proper altitude. Improved and reduced in size, this fuze was also used in the Mark IV. Major improvements, first fielded in the Mark IV bomb, began in 1949. These changes included upgrading the low-voltage battery that powered the radar to one requiring a single day to charge, and protection against enemy countermeasures — revealed by intelligence sources — that might jam Archie radar fuzes.

Sandia's first significant improvement for the Mark III was to redesign the firing subsystem that stored energy for release in the precise form needed to fire the detonators. The original system used aircraft electrical power because the low-voltage batteries in the bomb were marginal in capacity. This created a safety problem for the aircraft crew since the bomb was partially armed in flight. The solution was to develop a firing set that could be charged rapidly after release of the bomb from the aircraft. This new system significantly reduced both the battery charging time and x-unit weight.

The Mark III had a heavy steel case to protect it from antiaircraft fire. Its ellipsoidal shape resembled that of a watermelon, and because Sandia is a Spanish word meaning watermelon, wags referred to Sandia as the "watermelon laboratory." Such a watermelon shape released from an aircraft tumbled end over end, so tail fins were installed to keep its radar pointed at the target. However, the bomb wobbled unsteadily during free fall. Notably, both the Nagasaki drop and the 1946 Crossroads drop were off center target.

The Mark IV development program was authorized by the AEC concurrently with the Mark III, its goal being "to engineer the Mark III into a device that could be easily

Weaponeer Leon Smith was part of the engineering team responsible for arming and fuzing the Little Boy and Fat Man bombs. He joined Sandia's bomb fuzing group in 1947, initiated systems engineering in 1955, and directed the components, weapons development, and monitoring systems groups before retiring in 1988.

assembled by the military and stored in the assembled form" and could be produced in the AEC's integrated contractor complex that became operational by the late-1940s to replace some Los Alamos and Sandia facilities. In fall 1947, about midway in the development program, AEC priority shifted suddenly to the first series of full-scale nuclear tests for weapon development purposes, Operation Sandstone, at Enewetak Atoll in the Pacific Ocean.

Sandia's associate director, Robert W. Henderson, was appointed First Assistant Scientific Director to assume overall responsibility for technical support of the operation that would eventually involve over 10,000 people and hundreds of ships, motor vehicles, and aircraft. Henderson drew many of his technical staff from Sandia, including Jack Howard, Glenn Fowler, Don Cotter, Lou Hopkins, Art Machen, and Leon Smith. Upon completion of the last of the three tests on May 15, 1948, the task group began to disband and Sandians returned to the Mark IV project. This episode of essentially immediate redeployment of technical and administrative support staff to a new nationally defined urgent task marked the first in a series of remarkable events over the years that characterize one of the precious resources provided to the country by a national laboratory.

By 1950, the Mark IV Mod 1 had evolved into the Mark 6 (as model numbers grew, arabic numerals were used). This new weapon featured a jamming-resistant radar fuze that could be reset for different height-of-burst options, improved ballistic performance, a contact fuzing option, and, most importantly, a mechanical in-flight insertion mechanism. Now the crew of the aircraft could insert the capsule in much less time than had been required by earlier designs. The scientist was finally out of the bomb bay. The development for the Mark 6 Mod 2 was a brief two years and production began in early 1952, with later modifications following quickly.

In 1946, Sandia's field test group, under Glenn Fowler, had established two test ranges for ballistic and related tests of the bombs. A temporary range with mobile equipment was opened near Los Lunas, New Mexico for tests flown out of Kirtland Field. Sandians helped load the inert test bombs, then motored the thirty miles to Los Lunas while the B-29s struggled to raise several tons of bomb to about 30,000 feet for the drop. Fowler's field test unit tracked bomb trajectories with Askania phototheodolites, developed by German optical experts to track the V-1 buzz bombs. The telemetry group installed instrumentation in the inert bombs to record performance data.

In the same year, because the Los Lunas range was nearly a mile in elevation, Fowler arranged for the use of an old Navy test range with an elevation of 200 feet below sea level at the Salton Sea in southern California. This permitted assessing bomb ballistics at all elevations, and the Salton Sea base served as Sandia's principal test range until 1960. About 100 Sandians worked there full time during the 1950s, living in temporary housing and using a lodge and restaurant built by the AEC.

Military staff cars line the street outside Building 818, headquarters for Sandia Base and Z-division until 1949. To the left is the base chapel.

THE BRADBURY INITIATIVE

By 1948, the AEC had begun forming an integrated contractor complex to supplant or supplement the complex created during wartime by General Groves and the Army. At Kansas City, the AEC contracted with Bendix Aviation to open a plant for the production of electrical and electro-mechanical weapon parts, replacing the Army's Rock Island Arsenal. This move sparked Los Alamos and the University of California to request that they be relieved of responsibility for production engineering and assembly at Sandia Laboratory.

Reviewing Larsen's expansion plans for Sandia in late 1948, Bradbury was disturbed to learn that Sandia would have 1300 employees at work in 1949. Questioning why Sandia should have a staff the size of Los Alamos, which was "responsible not only for the basic nuclear development, but for fundamental research in a variety of fields," Bradbury directed Larsen to stop hiring while he and the university reconsidered the future. Bradbury concluded that the University of California's contract responsibilities at Sandia should be limited to engineering, and the university's leadership concurred. He therefore proposed administrative transfer of Sandia's Road department, the production engineering arm, to the Bendix Corporation at Kansas City. Bendix would produce the Mark III while Sandia designed the Mark IV and improved future weapons.

Larsen objected strenuously to the Bendix proposal, citing personal experience. He had seen management of proximity-fuze development at the Applied Physics Laboratory shared by Johns Hopkins University for research and an industrial contractor for production, and he considered that arrangement a failure. He suggested that the AEC centralize responsibility for weapon quality and performance in the laboratory that was responsible for their original design and development. "Close technical coordination must exist between weapon research and development, the ensuing production engineering phase, and the final acceptance of the end products," averred Larsen, "to insure that they meet the original required and planned specifications."

Larsen countered Bradbury's initiative with an offer to form a non-profit corporation to be named Sandia Laboratory, Inc., to manage Sandia as a whole. Sandia would incorporate and manage itself under AEC guidance. This plan did not meet with approval from the Air Force, which recommended that the AEC seek an engineering firm as the contract manager for Sandia — perhaps General Electric, North American Aviation, or Borg-Warner.

SEARCH FOR INDUSTRIAL MANAGEMENT

While the debate over Sandia's future continued, AEC chairman Lilienthal had turned to industrial contractor-operators, not only for production facilities but also for laboratories in some instances. At the end of 1947, for example, he selected Union Carbide to replace the University of Chicago for the management of Oak Ridge National Laboratory. He was predisposed, therefore, to search for an industrial manager for Sandia in November 1948 when the University of California announced its wish to withdraw entirely from Sandia and asked that the AEC select another contractor by July 1949.

At this news, Roger Warner, who had left Sandia to become AEC Director of Engineering, joined with General James McCormack, AEC Director of Military Applications, and James Fisk, AEC Director of Research, in a survey of industrial candidates for Sandia's management. Because Sandia provided "the connection between Los Alamos and the airplanes," they considered this the most important management decision they had made so far in the weapons business. They were interested in recruiting Bell Laboratories for the job. Fisk had worked for Bell Laboratories during the war, and eventually became its president. In addition, Oliver Buckley, president of Bell Laboratories in 1949, also served on the AEC General Advisory Committee. Fisk and McCormack approached Buckley, who agreed to allow time for Mervin Kelly, Bell's director of research, to study the Los Alamos and Sandia situation. As an individual, not as a representative of Bell, Kelly agreed to undertake an independent study of conditions at Sandia. He specified that he would not name any firm to assume charge of Sandia, nor would he submit a written report.

A former student of famed physicist Robert Millikan at the University of Chicago, Kelly joined AT&T in 1918 and patented improvements in vacuum tubes and transoceanic telephone service. He became director of research for Bell Laboratories in 1936 and managed substantial contributions from Bell to the national defense during World War II. Kelly took Bell Laboratories to first-rank leadership through his insistence that it sponsor fundamental research in addition to empirical, cut-and-try methodology. He made Fisk his assistant for physical research and employed such theoretical physicists as William Shockley and John Bardeen. Their Nobel prize-winning success in devising the transistor in 1948 brought Kelly renown as an industrial research manager. It is noteworthy that Kelly employed young researchers in transistor and solid state sciences such as John Hornbeck, Morgan Sparks, and George Dacey, each of whom would, in time, serve as president of Sandia.

In company with General McCormack, Kelly paid an extended visit to Sandia during the spring of 1949. On May 4, he presented his report to the AEC and an audience that included Paul Larsen. Kelly reported that work at Sandia was hampered by several crash programs forced on it by military requirements and by the university's

Mervin "Joe" Kelly, president of Bell Laboratories, recommended the formation of Sandia Corporation in 1949 and was later instrumental in moving Sandia toward enhancement of weapon development engineering capabilities.

disinterest in production and purchasing obligations. He urged the AEC to quickly select another manager — not another university, not an independent corporation (as Larsen proposed), and not the AEC directly with civil service employees. Sandia should be managed by a large industrial firm with considerable experience in defense programs.

Although Kelly refused to specify a firm, by May the AEC had settled on AT&T as its primary candidate. Sensing reluctance from AT&T, Lilienthal discussed the situation with President Truman, and on May 13 the President dispatched an appeal to the patriotism of the president of AT&T, Leroy Wilson. Sandia's work was critical to national defense, Truman stated, adding, "you have here an opportunity to render an exceptional service in the national interest." "Exceptional service in the national interest" has since become Sandia's rubric.

When Wilson replied that he would think it over, Lilienthal and his assistants spent Memorial Day of 1949 at Wilson's home, pressing their case. Wilson protested that AT&T had more than enough defense contracts underway, notably development of the Nike missile guidance and control system. Moreover, AT&T was defending itself against a federal anti-trust lawsuit, and Wilson thought it ironic that one branch of government demanded AT&T's services while another branch sought to dismantle its valuable research and industrial capabilities.

Lilienthal explained to Wilson that "laboratory" inadequately described Sandia, which performed "many tasks beyond those normal to a laboratory." Its principal laboratory function included supporting the design and development of weapons and the equipment for handling and testing them. In addition, Sandia was responsible for purchasing and producing weapon parts; for completing drawings and specifications needed for manufacturing the parts; for scheduling deliveries and assuring product quality; and for monitoring weapon quality throughout stockpile life. It also operated the Salton Sea test range, wrote maintenance and operations manuals, and trained the armed forces teams who deployed weapons in the field.

Pointing out that Sandia had 1400 employees and an annual budget of more than $10 million, Lilienthal told Wilson that AT&T would be expected to take the entire package, including the test range and the housekeeping work then done by the 160-member staff of the AEC Santa Fe office. "It is of the highest importance to the atomic weapons program," Lilienthal stressed, "that the organization at Sandia be the strongest organization that it is possible to obtain."

As a follow-up, McCormack met with Wilson in June at AT&T headquarters in New York. Within the Bell system, AT&T and its subsidiary Western Electric shared ownership of Bell Laboratories. Wilson assigned the Sandia contract negotiation and management to Stanley Bracken, president, and Walter Brown, vice president and general counsel, of Western Electric. A Western Electric team took charge of the project and toured Los Alamos and Sandia during July. After they visited Los Alamos, Norris Bradbury told the University of California regents that action would be swift. "The boys have had their marching orders...," Bradbury said, "to take on this project and make a success of it."

Intentionally or not, AT&T had achieved an enviable position. Because the AEC had insisted over the corporation's objections, AT&T could dictate the contract terms and name its price. But AT&T did not press this advantage, insisting instead on a no-profit, no-loss contract, not even asking for an account to cover overhead. Although some AEC staff urged that AT&T should be required to accept a profit, to give the government leverage in performance assessment, the AEC accepted this unique contract arrangement. Over time, it saved the taxpayers hundreds of millions of dollars, and absolved AT&T of the "merchants of death" accusations that plagued defense contractors during and after the world wars. When AEC counsel prepared a detailed contract, Western rejected it and proposed a brief, single-page contract requiring that Sandia be managed according to good industrial practices. Although longer than one page, the final contract signed in October 1949 was indeed brief and essentially required management of Sandia in accordance with AT&T industrial standards.

For two reasons, Western Electric incorporated Sandia Corporation, a wholly owned subsidiary, to manage Sandia. First, under University of California management, policies had been established at Sandia that Western Electric did not want to extend to its own operations. Second, the AEC wanted Sandia to stand on its own as a corporation in order to facilitate transfer of it as an entity to another contract operator should AT&T decide to withdraw. Formed under Delaware law with stock worth $1,000, all owned by AT&T and invested in U.S. savings bonds, Sandia Corporation began managing Sandia on November 1, 1949. Just as the AEC had planned, when AT&T withdrew from the contract forty-four years later, the Sandia Corporation transferred smoothly as an entity to the new contract operator and continued to manage the Laboratories.

George Landry, Western Electric executive, served as Sandia's first president from November 1949 until February 1952.

LANDRY MANAGEMENT

When the Sandia Corporation board of directors first convened at AT&T headquarters in New York, it included four members, all from Western Electric and none from Bell Laboratories or other elements of the AT&T system. They elected George Landry, one of their number, as Sandia's first president.

Landry was a New Yorker who had joined Western Electric in 1911 and rose to manage its Hawthorne and Kearny manufacturing plants and serve during the war on the Federal War Production Board. He had devoted his career to increasing and improving industrial production. Before Landry came west to Sandia, Western's executives assured him that he had an easy job ahead, because Sandia was an existing operation, rather than one that Western had to create outright. Landry later complained that this proved rather a disadvantage. He landed at Sandia in the midst of turmoil, with morale low and employees fearful of the changes new management would bring. To ease the transition, Landry attempted to keep Paul Larsen on, but Larsen left for Washington to become director of the Office of Civilian Mobilization, the national civil defense program.

Accustomed at Western Electric to a sharp distinction between management and labor, Landry was uncomfortable with the first-name informality he inherited at Sandia from Los Alamos and its university management. His efforts to implement Western's industrial practices encountered lively opposition, especially his attempts to reduce the amount of annual vacation that had been allowed under university management. Sandia had no labor unions when Landry arrived, but organizers used the proposed vacation curtailment as a rallying cry and within months Landry faced negotiations with three unions, eventually conceding.

Landry found Sandia's physical plant in the throes of new construction, with muddy or dusty unpaved streets and trenches opened across the entire area for utility lines. The new permanent buildings were intended to replace the temporary frame structures built by the Army, but urgent defense needs forced a threefold increase in personnel and space requirements at Sandia. It proved impossible to raze the temporary buildings. They remained in service; and one, Building 828, was still in use almost a half century later.

This recruitment poster reflects Sandia's rapid growth to 4,000 employees under Landry's management.

As expected by the AEC, Landry brought a top Western Electric management team with him and inserted it atop the existing organization. To the surprise of veteran Sandians, Landry's executive team of four included only a single Bell Laboratories representative, Robert Poole, who transferred from the Nike missile program to become Sandia's director of research and development. Earlier, Poole had formed Bell's Whippany laboratory for military electronics. This new management encountered resentment from some of the employees.

Landry met resentment from the greater Albuquerque community as well. Sandia was largely a "company town." Not everyone had automobiles for commuting, and the AEC housing area had waiting lists. Separated geographically from the city, Sandians used military base facilities and flocked to the Coronado Club, a restaurant and social center opened in 1950. Sandia's personnel director, Ray Powell, observed that some people in Albuquerque considered Sandians to be "intruders on the mesa." As the contract specified, Landry and Sandia Corporation replaced the AEC as the landlord for this community, along with the housing at Salton Sea, the motor pool, and the security forces. This freed the AEC from the headaches of facilities maintenance such as planting the grounds, repairing utility services, and cleaning dormitories. It was to be another decade before Sandians no longer needed the housing area and amalgamated into greater Albuquerque.

In an effort to ameliorate some of these difficulties, Landry formed a public relations department under Ted Sherwin. To better inform employees, Sherwin began publication of a newsletter, replacing a mimeographed bulletin distributed in Larsen's days. It disconcerted Sherwin when Landry personally reviewed and revised each issue. Landry apparently subscribed to the philosophy that the best public relations year is one in which the firm is not mentioned in the newspapers. If so, he must have been pleased in 1950. Although the *New York Times* noted the existence of Sandia in 1948 and 1949, in 1950 it did not mention Sandia at all. For improved community relations locally, however, Sherwin and Ray Powell established liaison with Albuquerque leaders, and Sandians soon became involved in civic affairs. Sandia vice president and first general manager, Tim Shea, became chairman of Albuquerque's United Way campaign in 1951.

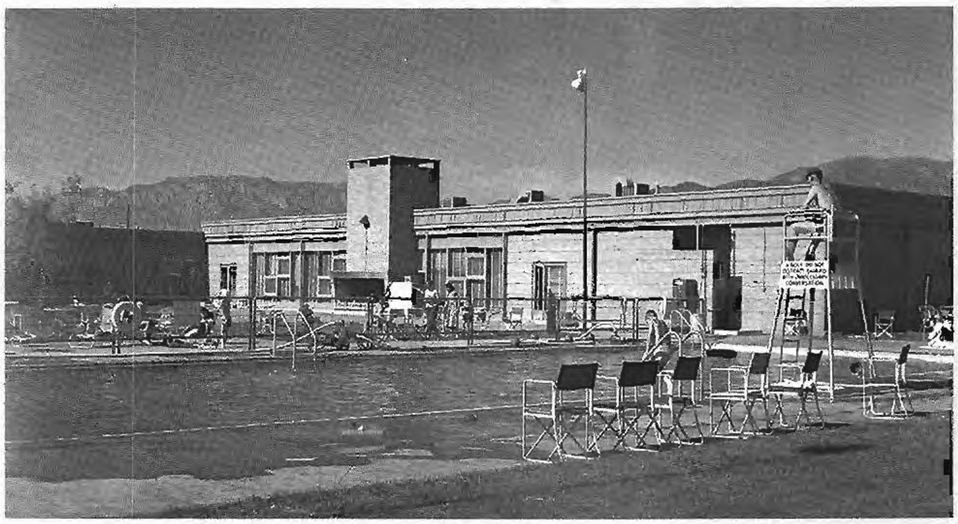
The University of California had managed purchasing for Sandia out of its Los Angeles business office, and Landry had to create a new purchasing organization at Sandia. Hardy Ross and William Dietrich led the group of three dozen purchasing officers imported from Western Electric to centralize purchasing at Sandia. This organization soon was placing 3,000 orders monthly with manufacturers throughout the nation.

Landry also reorganized and augmented the Road department in the Western Electric style, with distinct lines of management headed by superintendents. Walter Pagenkopf and Lyle Biskner were placed in charge of this new production engineering organization. This involved fundamental changes for the design engineers, accustomed to working directly with the craftsmen in translating the designs into production. Before Western took charge, responsibilities had been fuzzy. "In many cases, we had craftsmen who had more experience with mechanical or electronic design than some of the engineers," said Corry McDonald. "We had some of the engineers actually doing some of the drafting; when they finished the initial phase, they'd take their drawings to the shop and get it built." Landry ended this cooperative interaction, and not all Sandians approved.

EMERGENCY CAPABILITY FISSION BOMBS

Volume production often forces breaks with the past, and Landry faced volume requirements soon after his arrival. In August 1949 the Soviet Union had detonated its first nuclear device. Its monopoly ended, the United States felt vulnerable, and national defense interests demanded expedited production from Sandia and the growing AEC weapons production complex. Then, barely had Landry settled in his office when the

To enhance morale and community relations, Landry established the employee services and public relations department. *Left to right:* Eugene Peirce, department manager; Kenneth Smith, supervisor of employee services; Ted Sherwin, supervisor of public relations.



A view of the Coronado Club's swimming pool and patio area in the 1950s.

Coronado Club

When the Coronado Club first opened its doors on June 9, 1950, with a gala dinner dance, it was essentially a unique facility in Albuquerque, one of very few that could accommodate large groups. At that time, Sandia Base was an isolated facility six miles from Albuquerque and many Sandia and AEC employees still lived on base. The new Club's purpose was to serve as a community recreation center for the use of Sandia and AEC employees, providing them with facilities equivalent to those of the military.

The original Coronado Club consisted of the ballroom and restaurant facilities and a single swimming pool. The basement held a four-lane bowling alley, game rooms for ping pong and pool tables, and a small party room. In 1956, a second pool was added, and in 1965 the basement was completely rebuilt, eliminating the bowling alley and game rooms. These were replaced with a Sandia training facility used for work-related courses, organizational meetings, and other corporate functions.

Despite Albuquerque's dramatic growth beginning in the 1960s and continuing into the 1990s, and the attendant expansion of recreational facilities of all kinds, the Coronado Club retained its popularity with Sandia employees as a pleasant, inexpensive place to take their families. The Club has arranged a multitude of functions aimed at different groups: children's film nights, teenage dances, singles nights, Sanado meetings (established in 1958 as a club for Sandia wives to help them acclimate to Albuquerque), bingo nights, and even a dog show. Attendance at the Coronado Club has reflected Sandia's cultural changes: At its inception, the Club was "the place to be" but as the years passed and the nature of the work force changed, it ceased to be the primary focus of Sandians' social activities.

Although Sandians have for the most part been law abiding and of exemplary behavior, there was a famous altercation in 1958 at the Coronado Club at an event called the Beachcombers Ball. A few male Sandians went swimming while inebriated, and the Club management decided to take action. When some members refused to leave the pool, the manager summoned the MPs. Those members at poolside were incensed and resisted the MPs, throwing one in the pool. Several celebrants were arrested and given light fines for drunkenness. A massive investigation by the Provost Marshall and the Club Board of Directors followed, which ended up with the New Mexico Congressional delegation and the AEC. Needless to say, that was the last Beachcombers Ball.

George Landry established Sandia's medical department in 1950, and it had this ambulance for emergency service. Arthur Chacon was the driver and Bernice Beeson the nurse.

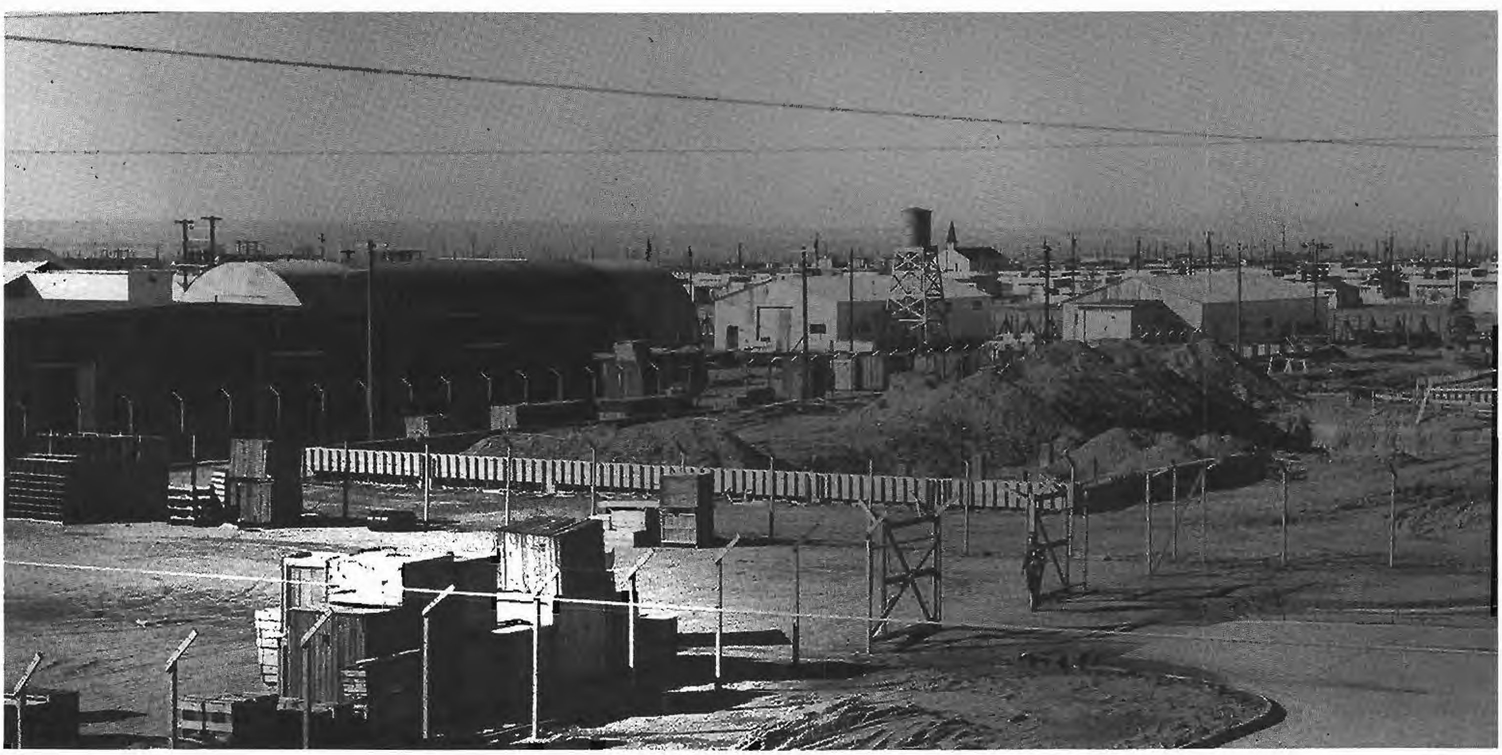
Korean war began. Two weeks later, he received a telegram, "Anticipating a military requirement not yet firm, you are directed to formulate a plan using all facilities at your disposal to deliver to War Reserve at the earliest possible date service models of the TX-5." TX-5 was the Test eXperimental version of the Mark 5. It was replaced by Mark nomenclature when the program was formally authorized.

In 1950 the Navy lacked an aircraft carrier with a deck long enough to get a plane airborne carrying the Mark III or IV implosion bombs. With smaller internal components, the Mark 5 bomb weighed less and had a 45-inch diameter compared with the Mark III's 60 inches. The TX-7, announced by Los Alamos in mid-1950, would be even smaller, weighing less than 60% of the TX-5 with a diameter 20% less. Furthermore, it had an inflight insertion mechanism developed at Sandia for improved operational readiness.

Partially to compensate for the loss of 160 employees who joined the military services in Korea, Sandia went to a six-day work week to meet its delivery schedules. Production of the Mark 5 began in 1951. That same year Sandia completed its design of the Mark 6, which replaced the steel case used in the Mark IV with an aluminum case, thereby reducing its weight by nearly 2,400 pounds.

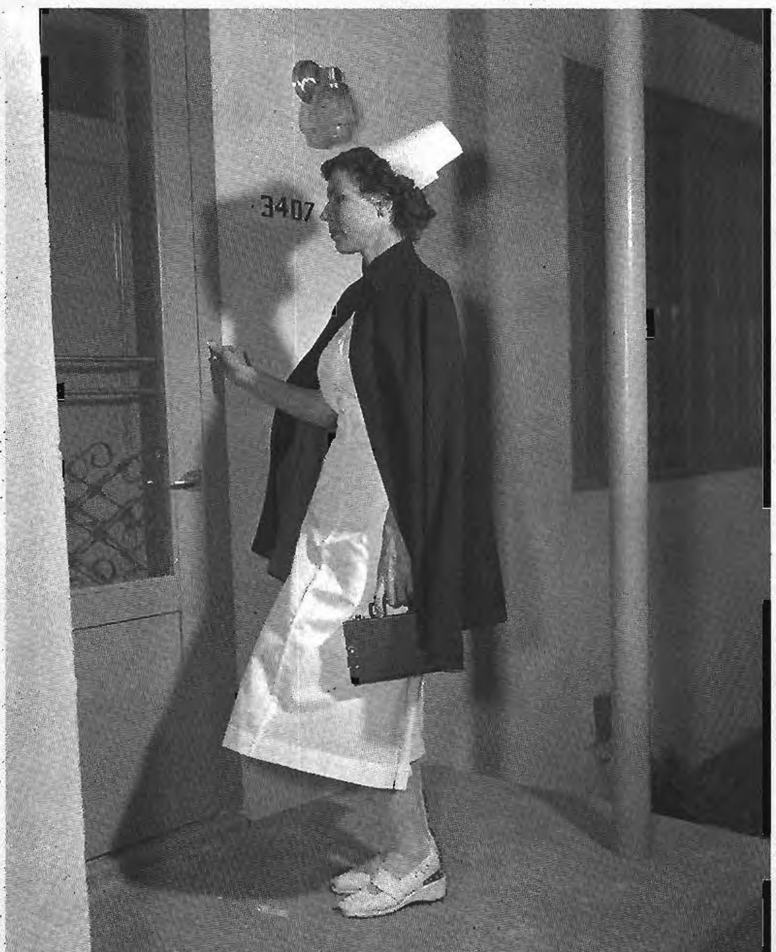
During the Korean war, Sandia accepted emergency capability programs, representing the peak of its weapon production efforts. Two of these, called the 4N and 7N programs, involved fabricating and delivering handmade samples of the Mark IV and Mark 7 bombs to the military services for use in a national emergency, if such an emergency occurred before full-scale production had begun. The Mark IV was a strategic bomb, a third-generation Fat Man incorporating several improvements in its design. "We rushed around like crazy," recalled Robert

Completed in 1949, Building 800 was Sandia's first permanent building and became one of its symbols. In this 1951 photograph, Building 802 is rising behind 800.



The construction of permanent facilities was well underway by the time George Landry and Sandia Corporation assumed charge of Sandia's management in 1949. In the center is the foundation excavation for building 860.

MAINTAINING A HEALTHY WORKPLACE



Sandia Visiting Nurse Mildred D. Whitten calling on an ill employee in 1951.

Sandia's medical organization

By the middle of the twentieth century, American corporations had taken the stand that a medical service would reduce the number of accidents and illnesses experienced by employees. The argument that a healthy worksite is a productive worksite has been convincingly illustrated in many industries over the years and Sandia has wholeheartedly adopted this position. From the beginning, Sandia's employees have had access to medical facilities at work. The two primary reasons for offering medical service are to render emergency care for injured or ill workers and to provide medical surveillance.

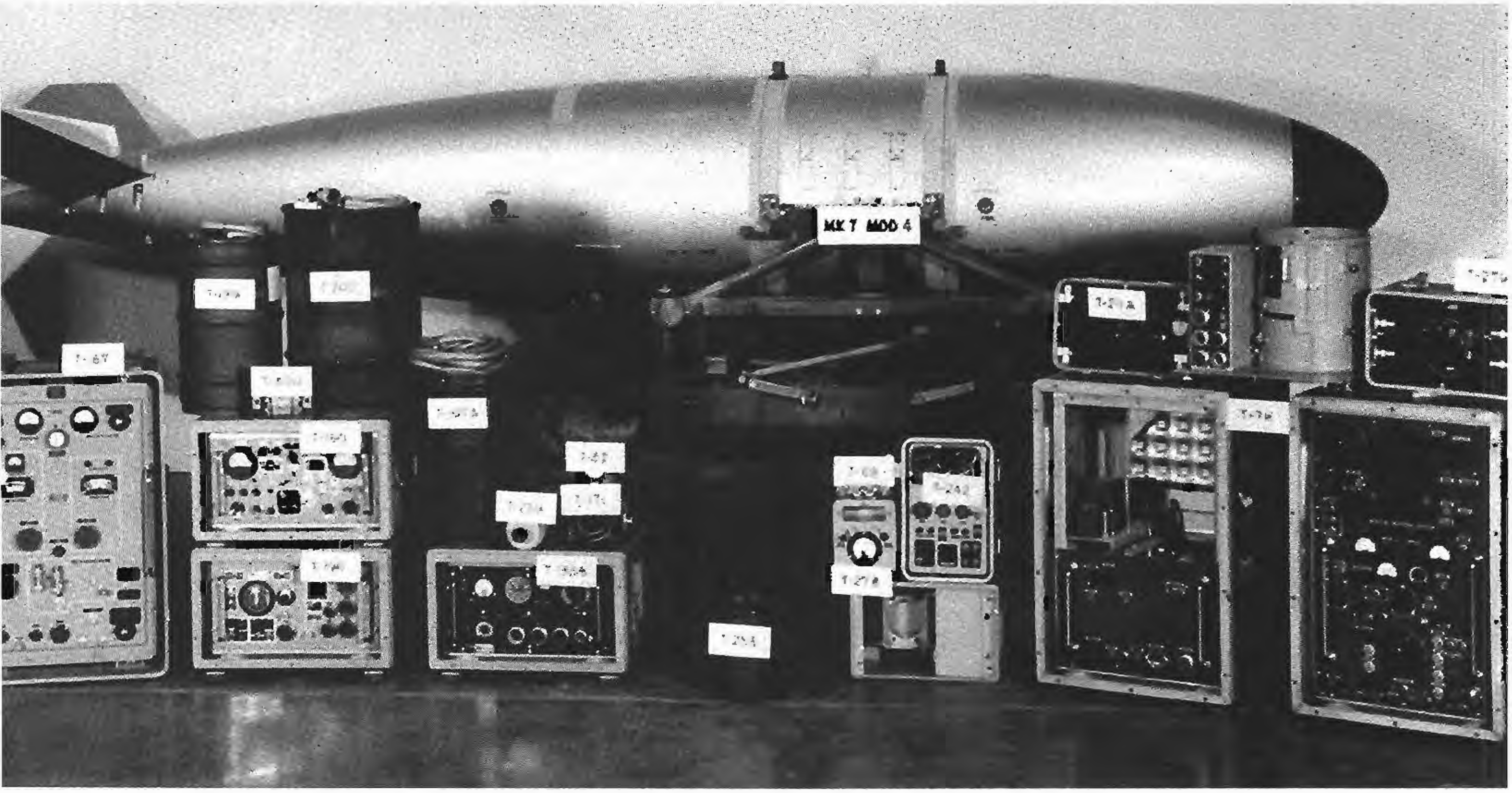
A well-trained medical staff has always been available at each of Sandia's sites to handle emergency care for employees. In addition, medical surveillance has been seen as an obligation from Sandia's early years. Departments devoted to industrial hygiene and radiation protection are responsible for evaluating and monitoring workplace environments with, in recent decades, specific attention to potential reproductive hazards. The medical staff, in conjunction with the medical surveillance program manager, decides at what point personnel require medical surveillance and determines other categories as new tasks or hazards are identified.

In addition to Sandia's on-site facilities, in the early years ill employees often had medical care come right to their door. Sandia's first visiting nurse was Mildred Whitten, who started the program in 1951 with an extensive background in industrial and military nursing. The purpose of the program was to make sure that an employee who had missed three days of work was receiving adequate medical care, was not neglected or alone, and that the time was appropriately charged to sick leave. Whitten frequently encountered entire families who had been taken ill and were unable to care for themselves. She would provide them with nursing care, call a doctor if necessary, and occasionally ended up shopping for groceries.

Beginning in 1949, Sandia made group health coverage available to all employees. Employees paid all premiums and made their payments directly to the carrier. When Sandia began sharing in the payments in 1958, the visiting nurse program was phased out. In addition to a concern with immediate health problems, Sandia's medical organization has also committed to helping employees become healthier and maintain their health in the long term through lifestyle, diet, and exercise classes. Begun in 1986, the Total Life Concept (TLC), later called SALUD, was patterned on an AT&T program designed to teach employees how to stay healthy, keep fit, and manage stress.

As Sandia's work has changed, different medical programs have been added. For example, as a result of the end of the Cold War, an increased emphasis on nonproliferation, and ongoing negotiations for nuclear weapon treaties, Sandians began to travel abroad more frequently in the 1990s. In response, the medical organization established an International Travel Clinic to offer appropriate vaccinations for travelers and to provide information on health conditions in various parts of the world.

In 1953, two of Sandia's five medical doctors were women. Here Dr. Charlotte Beeson and assistant Mary Murphy time an x-ray on a patient in the medical department's new radiographic room.



The Mark 7 became the first nuclear bomb that could be carried by fighter planes. As shown, its maintenance and testing required considerable equipment.

Stromberg of Sandia's 4N program, "trying to get enough components together for those bombs to be put into the readiness stockpile."

Donald Cotter served as project engineer for the Mark 7, the first tactical nuclear bomb. Only thirty inches in diameter, it was small enough to be carried externally on a fighter plane, and, because even its shape was security classified, it was disguised as an external fuel tank. To get it into the emergency stockpile, Sandia had to install an existing fuze, which meant it had to be dropped from high altitudes. Sandia's new challenge then became development of tactical fuzes and other systems that would permit fighter planes to deliver nuclear bombs at low altitudes and still escape the blast. This challenged Sandia during the 1950s to create contact fuzes and weapons that could be dropped on a target and then detonated after impact, giving the aircraft additional escape time.

For mechanical engineers, the small diameter drove the design of the capsule in-flight insertion mechanism. The electric motors for the insertion mechanism required better batteries and Sandia electrical engineers devised a longer lifetime battery with nickel-cadmium electrodes, reducing strike preparation time from one day to one hour. Aerodynamicists were challenged by the design of the radome nose, fins that could be rotated to be compatible with the large number of tactical jet aircraft that might carry the weapon, and by designs for dive brakes to prevent the bomb from exceeding Mach 1. Most of the arming, fuzing, and firing components were packaged in a cylindrical cartridge configuration that could be removed for assembly and electrical testing by the military weapon technicians, then being trained at Sandia Base.

Both the Mark 7 and the later Mark 12 bombs encountered roll-pitch coupling (aerodynamic resonance) in drop tests. Harold

Vaughn solved this problem by using fin tabs or canted fins. These techniques, along with spin rockets, were used on many subsequent bombs and rocket vehicles.

In addition, Sandia had a small group working with the Naval Ordnance Laboratory and the Army's Picatinny Arsenal on the design of such fission weapons as the Mark 8 and 9. These were gun-type weapons, operating on the principles used in the Little Boy bomb. The Navy's Mark 8 was designed to penetrate and destroy concrete submarine pens. A modification that never reached production, the Mark 11, provided a streamlined nosetip to allow its external carriage on fighter bombers. Because the Mark 8's functioning resembled that of the Little Boy (LB), it was called the "Elsie" (LC). Sandia's principal role in the Mark 8 design, in cooperation with Naval Ordnance, involved designing handling equipment and an aircraft saddle to carry the bomb.

The Army's Mark 9, the first nuclear artillery shell, was larger than conventional artillery shells and to fire it, the Army built a special 280-millimeter cannon. Although Sandia shared design responsibilities for this shell with the Army, it accomplished a significant design innovation in the telemetry for this project. Charged with designing instruments that could fit inside the shell and survive cannon firing to provide data on shell velocity and internal functioning, Glenn Fowler's telemetry group successfully designed a vacuum tube that could withstand the explosive shock. Following the Mark 9 experience, Fowler decided to convert Sandia's telemetry systems to transistors to achieve greater ruggedness. He reasoned that telemetry could become the proving ground for the use of solid-state electronics in weapons.

In 1953, the 280mm cannon on the left test fired a nuclear artillery shell seven miles down range. After designing testing telemetry for the shell, Sandia replaced vacuum tubes with transistors.

ASSEMBLY AND STORAGE

To assemble the high explosives for implosion-type bombs, Sandia in 1948 constructed an area south of and some distance from its original technical area. With buildings constructed to confine accidental blasts, this part of Sandia became known as Technical Area II, to distinguish it from the original site, now designated Technical Area I.

Work on emergency capability weapons gave rise to another challenge, code named Project Water Supply. During the late 1940s, the Army Corps of Engineers had begun the design and construction of underground storage sites for nuclear weapons. For site design, Richard Bice served as Sandia's project engineer and Jerry Jercinovic as liaison with the Corps of Engineers. By 1949, these sites began to open for service, and the AEC assigned weapon surveillance activities at these facilities to Sandia. Until 1960, Sandia stationed staff at the storage sites to monitor, maintain, and assemble the weapons. To ready a weapon for use, major components were tested and assembled with the assistance of military personnel. The weapons and nuclear cores remained in the custody of the AEC until the President of the United States authorized release of the weapon to the military. As many as two dozen Sandians worked at each of the storage sites opened at military bases across the nation. Intense security precautions required that they not mention where or for whom they worked, causing them considerable difficulty when, for example, they sought to open bank accounts.

WARHEADS FOR ROCKETS AND GUIDED MISSILES

As if the Korean War pressures were not enough, Sandia received additional challenges in 1950. Thanks to interactions with the German scientists who developed the wartime V-1 buzzbomb technology and were brought to White Sands at the end of the war, the armed forces had developed their own rockets and guided missiles, including air-breathing drones with turbojet engines that could penetrate to targets without endangering pilots or crews. By 1950, guided missiles such as the Matador and Regulus were being tested in the United States, and the military services wanted to arm them with nuclear warheads.

Although Sandia had become responsible for designing the components and casing surrounding the physics packages of nuclear bombs, that was not the case with missiles. Missiles supplanted and supplemented aircraft as delivery systems, and the military services asserted design responsibility for these just as they did for aircraft. Los Alamos would continue designing the nuclear package for either bombs or missile warheads, but Sandia's responsibilities were not so clear. Where did the design for a warhead end and the military design for the missile begin? A high-level debate of this question continued until 1953 when the AEC and DoD spelled out the division of their responsibilities.

While the debate was in progress, Sandia created a warhead engineering department managed initially by Lou Hopkins and undertook to identify a standard warhead design for all guided missiles. It used existing bomb packages as the warhead, and developed adaption kits to marry the warhead to different kinds of missiles. The warhead program moved quickly from the study stage in 1950 to design engineering in 1951, and by the end of that year it had begun to rival in size the bomb design programs at Sandia. New challenges in weapon design were heralded in November of 1952 by the U.S. detonation of Mike, the first large thermonuclear device, in the Pacific. During Landry's tenure, Sandia's yearly weapon design projects increased from two or three to ten or more.

FIRST REIMBURSABLE

Sandia initiated its first reimbursable program in 1950 when it accepted, with AEC permission, funding from the Defense department for a study of nuclear weapon

Building 904 in Sandia's Technical Area II was constructed in 1948 for the assembly of high explosives.

The Sandia motor pool was managed by the military until 1950.

To launch Sandia's 1951 campaign for the Albuquerque Community Chest (United Way), George Landry and actress Greer Garson conducted a live radio broadcast at the Sandia base theater.

effects. Because nuclear weapons at the time were low yield in comparison with later designs, it was important to the military services to understand how to maximize their effects — the damage they would cause to the enemy.

Early nuclear testing indicated that the effects on structures might be understood if fundamental principles of airblast loading could be established. At the request of the Armed Forces Special Weapons Project, Sandia began studies of blast loading on structures, using high explosives and small model structures. Research director Robert Peterson employed such specialists as Harlan Lenander and Luke Vortman for this work. Jack Howard managed the explosives tests in Coyote Canyon, south of Sandia's main area, while others went to the Pacific to instrument structures during atmospheric tests and analyze nuclear blast results.

In 1950, the AEC established the Nevada Test Site (NTS) north of Las Vegas to conduct nuclear tests, and a group of Sandia scientists led by Everett Cox, James Reed, Byron Murphey, George Hansche, and Melvin Merritt focused on blast and other weapon effects at the new site. These studies introduced them to curious sound and shock wave effects that seemed to skip and return to the earth at points quite distant from the test site. A summary of this research appeared under the byline of Everett Cox in a 1953 issue of *Scientific American*. Its publication brought Sandia its first widespread recognition for research.

Pressures on Landry to further increase Sandia's capabilities continued, coming from such authorities as General McCormack, who recommended that Sandia check any tendencies toward emphasis on routine and minor economies. "Nothing at Sandia must hold back development and engineering," warned McCormack, "except the rate of invention." A decade later, Frank Neilson would tell Orval Jones that, "here, money is like oil, you squirt it on to make things go faster."

Systems analysis began in earnest at Sandia in 1951 with the formation of a weapons reliability committee chaired by Walter MacNair and assisted by Robert Peterson of Sandia, Robert Prim and consultant Hendrick Bode of Bell Laboratories, the latter a pioneer in systems engineering. Their report, issued in December 1952, became a classic, concluding that nuclear weapons were special, not conventional, having a complexity not subject to verification in peacetime. The report set standards for weapons reliability that became the goals of Sandia's design engineers. In 1951, Sandia created its systems evaluation department, oriented toward mathematical and statistical modeling. Within a few years, its systems analysis findings significantly influenced nuclear weapon design.

Posed before Sandia's West Lab facility in early 1952 were Sandia's management and first scientists. *Front row, from left:* Robert Poole, George Landry, Donald Quarles, Mervin Kelly, and Robert Petersen. Behind and to the right of Quarles is George Hansche, the first scientist to continue at Sandia until his retirement.

GREENFRUIT INVESTIGATIONS

Radar fuzes for bombs had continually been the foremost challenge to Sandia's development groups, both because of their complex technology and because of the difficulty of converting laboratory devices operating at high frequencies to hardware produced by industrial suppliers. By the end of 1951 serious quality concerns arose. Richard Bice, director of engineering, noted there were serious reliability concerns about a radar fuze for which the manufacturer could not meet quality criteria. Nor were the 4N and 7N emergency capability weapons up to standards; they were tool-made prototypes released at urgent military request before the designs went into production.

Investigations of quality began, and one of them, led by Tom Marker and focusing on problems with the MC-1 radar, was named the Greenfruit (for "unripe" designs) study by one of the task force members. Other studies considered weapons quality generally, and their recommendations resulted in the formation of an independent quality assurance organization at Sandia. Some critics thought the quality problems so serious that Sandia should be returned to military management. Mervin Kelly of Bell Laboratories quickly quashed that notion and warned that AT&T would withdraw from its contract in that case.

A shift in Sandia's management began when the corporation board of directors added two members from Bell Laboratories, Kelly and Donald Quarles. In February 1952, George Landry resigned as president of Sandia to be replaced by Quarles. Landry returned to Western Electric, but continued to serve on Sandia's board until 1954.

A team of investigators appointed by the AEC and AT&T subsequently studied Landry's management, especially employee morale during those years. First, the team reported,

Among the soldiers from Project W-47 at Wendover airfield who later joined Sandia and posed for this 1956 portrait were, *front row, from left:* Chester Morterud, Al Hall, Manuel Bolton, James Les Rowe, Bryan E. "Jim" Arthur. *Back row:* Harley "Eddie" Walker, Albert Mandell, James McGovern, Leon Smith, G. C. Hollowwa.

the transition from university to corporate management forced 1,740 employees to adjust to new operating systems. Second, this transition occurred while nuclear weapons were becoming more complex and during crash production schedules. Third, it transpired at a time when Sandia's work force trebled and as production increasingly was contracted out. Personnel who formerly had supervised in detail the progress of a component from design to the stockpile had to share their responsibilities with others. These fundamental changes inevitably affected morale.

Years later, Kelly commented that under Landry's management too much emphasis was placed on preproduction, manufacturing control, and contracting aspects. Experience showed the necessity for greater organizational emphasis on the development aspects of the job, Kelly concluded, "which led to the assignment of a Bell Laboratories man to the chief executive position."

ANSWERING THE QUESTION

How should nuclear weapons be managed? After six turbulent, formative years Sandia had its answer: by creating and applying innovative but sound engineering to the major programs of systems development, component development, and field testing. In addition, it was recognized that high standards of performance for applied research and the supporting tasks of engineering for production, quality assurance, and surveillance were critical. This approach was instrumental in the process of equipping the military services with nuclear bombs that would provide the degree of effectiveness, readiness, and flexibility consistent with high levels of reliability and safety.

At the same time, the burdensome tasks of maintenance, assembly, and training during peacetime were reduced appreciably by innovative design measures. Transformed from a handful of nuclear weapons for a single type of bomber after World War II, the stockpile offered both strategic and tactical bombs capable of being delivered by a variety of aircraft, some operating at transonic speeds. To do this, the Los Alamos-Sandia team was able to reduce weapon size and weight by large fractions, both done at militarily useful nuclear yields.

In this process, Sandia set in motion a number of technological specializations that over the years would yield payoffs in enhanced weapon capabilities, as well as contribute significantly to other national security programs. The expedient approaches to problem-solving that had characterized the weapon program during World War II, such as cut-and-try, trial and error, overkill, extreme redundancy, small-scale model tests, and overlapping designs gave way to an increasingly orderly, measured development cycle. The process also effectively met a series of "emergency capability" needs to provide a small number of prototype weapons that could fill immediate national defense needs.

Roger Warner described the production and assembly of the early Mark models as an "occult art." Later, Sandian Del Olson referred to it as "black magic engineering." Although the general public may have thought there was something mystical about atomic weaponeering, that was not what Warner and Olson meant. They implied nothing mystical, but referred to the empirical cut-and-try engineering inherited from the Manhattan Project.

While the development of nuclear explosives at Los Alamos certainly was science based, weapons engineering at Sandia during its formative years generally was not. This was one reason why the University of California withdrew from Sandia's management. And while the military services and Defense department often funded such research projects as the proximity-fuze program, their intense interest in advanced engineering came only on the heels of Sputnik in 1957, when the Advanced Research Projects Agency began pumping funding into research.

Landry and Western Electric's management of Sandia Corporation from 1949 to 1952 aimed at organizing and increasing Sandia's production capabilities. But in the rush to meet emergency military demands, quality was necessarily secondary to output.

The election of Mervin Kelly of Bell Laboratories to Sandia's corporate board in 1952 marked a turning point in Sandia's history. Although he never served as Sandia's president, he gave the facility personal attention for the remainder of his career. Even later, while serving as president of Bell Laboratories, he continually commuted from New York to spend one week out of six at Sandia. His objective at Sandia was to make organizational changes that would allow the engineering groups to concentrate on the weapon development phase.

II

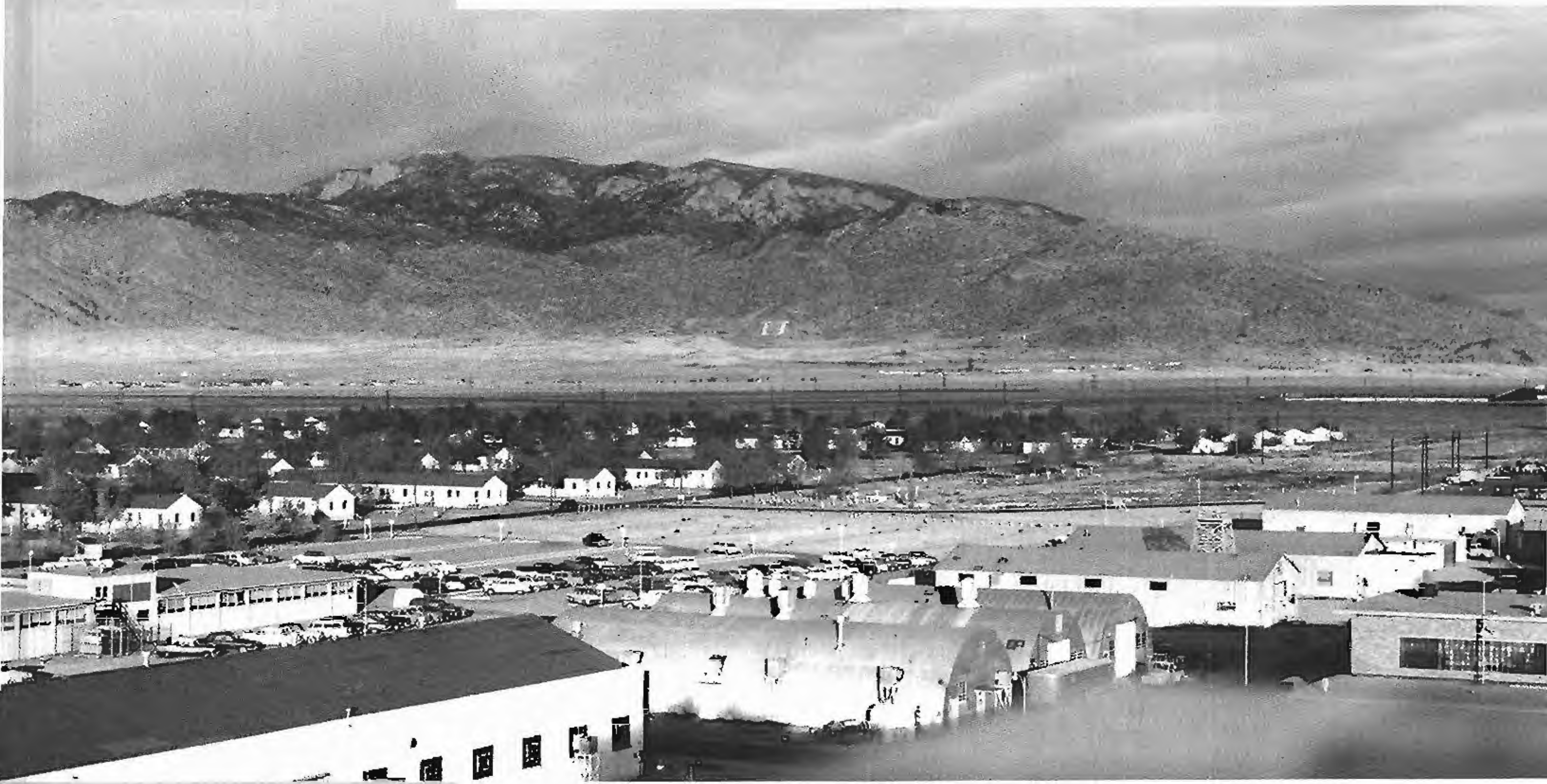
THE EISENHOWER BUILDUP

We must make sure that the quality and quantity of our military weapons command such respect as to dissuade any other nation from the temptation of aggression. Thus, we develop weapons, not to wage war, but to prevent war.

Dwight Eisenhower

The pace of nuclear weapon development in the United States peaked during President Eisenhower's administration. During the 1950s, the Atomic Energy Commission (AEC) completed its integrated contractor complex to meet a massive production schedule. Large jet aircraft capable of high-speed delivery replaced the B-29 and other propeller-driven bombers. The military services acquired missiles tailored to their individual needs and requested that they be armed with nuclear warheads. Facing a growing Soviet submarine force, the Navy urged the development of antisubmarine weapons, and, for threats against Korea and Europe, the Army required nuclear-capable battlefield weapons. By the end of Eisenhower's administration, Sandia had undertaken nearly sixty bomb and warhead application programs.

Design parameters for nuclear weapons evolved rapidly. Since 1946, Sandia's designs


A 1959 view of the Sandia Mountains shows Sandia's temporary buildings in the foreground.

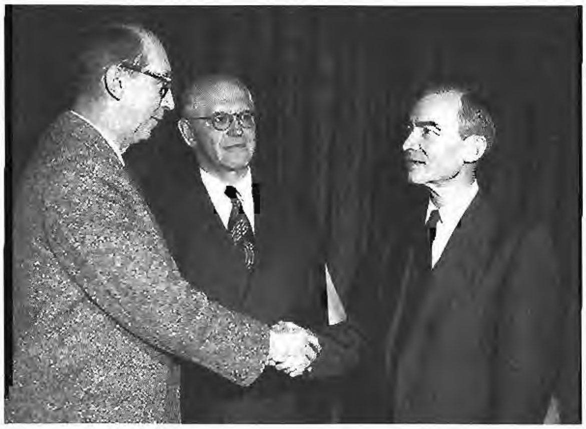
had been for fission weapons. Successful testing in 1952 and 1954 resulted in the addition of fusion, or thermonuclear, weapons, and Soviet tests of fusion weapons in 1953 and 1955 added to international tension and to the sense of urgency at Sandia. The 1952 formation of Lawrence Livermore Laboratory to compete with Los Alamos in the design of nuclear explosives increased Sandia's responsibilities. Sandia sent staff to California to support the Livermore activity, and made available its resources in Albuquerque to avoid costly duplication of these facilities in California.

With designs for smaller, lighter-weight warheads, and with the armed forces devising sophisticated new delivery methods, Sandia confronted complicated design challenges during the Eisenhower era. Its own initiatives included the "wooden," "building-block," and "laydown" bomb concepts that exist in most of today's nuclear weapons. The initiation of these concepts was the result of the leadership begun by Donald Quarles and continued by James McRae.

THE QUARLES REORGANIZATION

At his first press conference after replacing George Landry in March 1952, Donald Quarles bluntly told reporters of Sandia's mission: to convert the Los Alamos nuclear explosive systems into deliverable weapons. He had heard many new concepts concerning the kinds, sizes, and shapes of these weapons. "Our job," Quarles summarized, "is to study these possibilities very carefully and to lay such information before the [Atomic Energy] Commission and the military as will enable them to make wise decisions as to the lines of development to be pursued."

An Arkansas native and Yale graduate, Quarles joined AT&T in 1919 and was supervising the Nike missile electronic-guidance project for Bell Laboratories when he came to Sandia. From the Nike project, he brought Walter MacNair and Stuart Hight to manage Sandia's research. To free time for his coordination with the AEC and the military



Daniel Worth of the AEC welcomes Donald Quarles to Sandia in March 1952, with George Landry, *center*, preparing to return to Western Electric.

services, he appointed Timothy Shea as Sandia's general manager for internal administration of facilities, personnel, and business matters. Quarles initiated weekly progress meetings with his vice presidents. For more than forty years, Sandians called this executive group the "small staff" to distinguish it from annual meetings of the "large staff" that included directors in addition to the vice presidents.

At his first executive staff meeting, Quarles noted that he had learned in Washington that the AEC headquarters had decided Sandia would no longer perform any production of war reserve weapons. The AEC intended to limit Sandia to the production of test prototypes, or to furnish the military with a few custom-made new weapons for use in national emergencies, meaning a direct threat to the United States or its allies in the North Atlantic Treaty Organization (NATO).

In 1952, Quarles elevated research from a directorate to a vice-presidency headed by MacNair, not so much to institute fundamental research as to encourage specialization in several areas of engineering. The new organization included four directorates — Research, Field Testing, Apparatus Engineering, and Electronics. The organization was named "Systems Research," which was defined as "studies to assure that each specialized part of any system must not, in itself, be optimized to the detriment of the whole." This innovative approach to problem-solving is attributed in part to Dr. Hendrick Bode's pioneering work at Bell Telephone Laboratories. Bode and MacNair had collaborated on a 1950 report that attempted to quantify the military worth of nuclear weapons. This report included a validation of the radar fuze concept, then involved in a competition with barometric fuzing, a concept favored by the military.

The advent of systems research at Sandia eventually led to the development of a world-class reliability evaluation program. This program developed a methodology for predicting and assessing the reliability of a given type of nuclear weapon by using mathematical models from the beginning of design, throughout the development, testing, and production process, and extending to feedback from actual stockpile experience.

Quarles created a pre-production group in May 1952 to assist in translating Sandia's designs into products that would be used in weapons. The existing production engineering group (formerly the Road

Sandians meet with Bell Laboratories leaders at Murray Hill, N.J. *Left to right:* James Fisk, George Hansche, Everett Cox, Hendrik Bode, Robert Petersen, Walter MacNair, Mervin Kelly, Robert Poole, Donald Quarles, R. Brown, Kenneth Erickson.

THE HUB OF AEC'S QA IN 1958

Jerry Curbow (Dale Products Inspector), Gilbert McGuinness, and D. G. Lewis (Sandia Field Representatives) review product plans during a 1958 visit to the Dale Plant in Albuquerque.

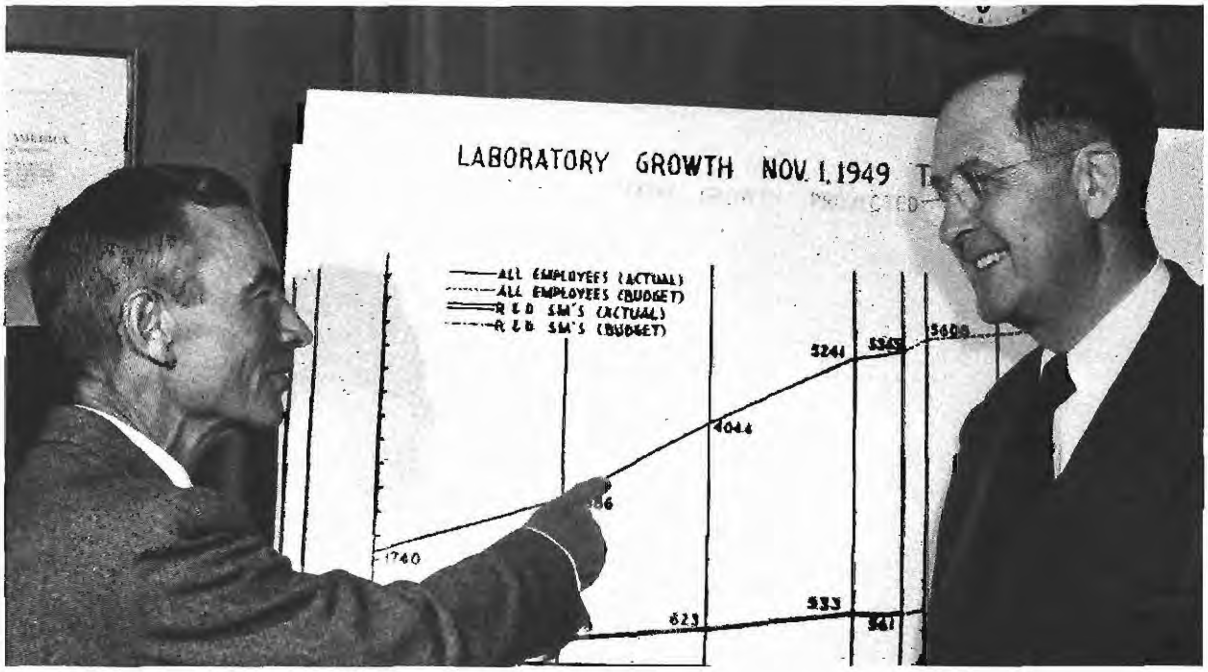
Quality Assurance

Quality Assurance concentrates on attaining high reliability and safety in products for the nuclear weapons program. Controls are applied to the manufacturing process to establish a high degree of conformance between specifications and weapon materials. In 1954, Sandia became the Quality Assurance Agency for the Atomic Energy Commission's (AEC) Sandia-designed material. As an outgrowth of the wooden bomb concept (completely assembled nuclear weapon in a high state of safe readiness), the rudiments of the modern Stockpile Sampling Program were born four years later in 1958.

In 1958, Sandia was the hub of AEC's Quality Assurance Operation. Sandia wrote rules, issued inspection procedures, carried out surveys, and staffed the quality assurance function at thirteen modification centers across the country. Fifty-nine field representatives who traveled in excess of 1,000,000 miles in a given year ensured that Sandia received high quality products. Their duties ranged from actual product inspections to providing advice on supplier quality control systems, and identifying factors influencing product quality. Field representatives served as the voice of Sandia Corporation. They were on the lookout for material defects and made sure the Quality Assurance Department was advised on test results. In the words of Harold Jeblick, Supervisor of the Field Inspection Division, it was the job of the field representatives to "establish and maintain good relations between a supplier and Sandia Corporation."

Sandia's quality assurance responsibilities changed significantly in later years. In 1961, all weapon production work transferred from Sandia to AEC integrated contractors; in 1975, ERDA took over the product acceptance function for Sandia-designed material; and in 1978 Field Operation was dissolved. Instead, the Stockpile Sampling Program expanded in scope and included responsibilities for developing and executing test and evaluation programs for nuclear weapons.

Building on its tradition of quality assurance, in 1989 Sandia introduced a Total Quality Program to its component development center. This quality initiative soon expanded throughout Sandia and reflected a strong customer focus aimed at developing reliable products efficiently, cost-effectively, and in a timely manner.



Donald Quarles reports on Sandia's growth to New Mexico Senator Clinton Anderson's satisfaction.

department) became the manufacturing development engineering department under Harvey Mehlhouse. Field inspection offices opened near AEC contractor production plants to assist with production-line design and quality testing. Sandia's production activities thereafter were limited to newly developed weapon parts that were not available from manufacturers. It pleased Quarles to report in 1952 that Sandia had placed 32,000 orders with 3,500 different industrial contractors. Even for its research and engineering development needs, Sandia contracted for assistance from eighty-eight different industrial, university, and military laboratories.

From Landry, Quarles inherited a young work force numbering about 4,000, with an average age of 32. About 20 percent of this number in 1952 were female and about 20 percent had moved to Albuquerque from outside New Mexico. Sandia employed few scientists and most of its middle managers were engineers; in fact, the majority were trained in electrical engineering. When electrical engineer Robert Peurifoy joined Sandia during the Korean War, he found work proceeding on a six-days-a-week schedule under intense, secretive conditions in the face of what seemed ominous Communist threats. "There was an immediacy, an urgency, with regard to doing everything possible to be responsive to national policy in growth of the stockpile and variety of weapon types," Peurifoy recalled. "Cost was of little consequence."

Quarles also personally presided over Sandia's negotiations with the military services on the design and production of arming and fuzing systems for missile warheads. For the early guided missiles, such as Matador, Regulus, and Corporal, and the short-range ballistic missile, Honest John, Sandia provided adaption kits that permitted use of explosive systems, such as the Mark 7, as missile warheads. This was accomplished amidst a top-level AEC and Department of Defense debate over the procedures to be used to develop the technical details of nuclear weapons. After a lengthy and sometimes contentious two-year negotiation with significant input from Quarles himself, a document was issued, informally known as "The 1953 AEC-DoD Agreement," which laid out the process for setting requirements and organizational responsibilities. This model, which would serve the system for decades to come with only minor modification, defined the six phases in a weapon's life cycle.

Weapon Life Cycle Phases:

Phase 1: Weapon Conception — the exchange of preliminary information that may lead to a feasibility study of a weapon program. Studies done by Los Alamos, Livermore, Sandia, and DoD, independently or cooperatively.

Phase 2: Feasibility — joint AEC, DoD, and contractor investigation of whether concept can be applied and manufactured. If weapon is seen as feasible, the AEC will issue a Phase 3 authorization for development of the weapon design.

Phase 3: Development — design definition. Engineering design and production planning lead to full-scale mockups for environmental and flight testing.

Phase 4: Pilot Production — designs are translated into production terms. Tool-made samples are fabricated.

Phase 5: Initial Production — manufacture and delivery of first units. This is the production engineering phase.

Phase 6: Quantity Production and Stockpile — units are produced in quantity and checked for quality both as they enter the stockpile and during their stockpile lifetime.

Later, Phase 7 was added: Retirement — weapon removed from the stockpile and returned to Pantex for disassembly.

During the final review and issuance of the 1953 "AEC-DoD agreement," the AEC, over the objection of Quarles and Sandia, also agreed to relinquish missile warhead arming and fuzing systems responsibility to the DoD and its contractors, codified as what came to be known as the "AEC-DoD Missiles and Rockets Agreement." Sandia's organization for designing warhead adaption kits, led by Louis Hopkins, closed abruptly, with some of its personnel transferring to Lockheed, Boeing, and other missile contractors. Thereafter, Sandia worked on missile warhead arming and fuzing systems only by request.

Responding to military requirements for an emergency supply of early fusion bombs, Sandia organized a fusion weapon design department under Eaton Draper, with Ray Brin, Lee Hollingsworth, and Leon Smith heading divisions for electrical, mechanical, and developmental testing. With an urgency driven by Soviet detonation of a fusion

Sandians assembling electronics during the 1950s.

President Dwight Eisenhower and his assistant, Frank Sanderson, muster Donald Quarles into the Defense Department.

James McRae came from Bell Laboratories to manage Sandia in 1953, when Donald Quarles went to the Defense Department.

device in 1953, Sandia's team sent designs to manufacturers at a swift pace.

The weaponization projects that began during Quarles's tenure included four Emergency Capability fusion bombs — TX14, TX16, TX17, and TX24; and the W7 (BOAR and BETTY for the Navy as well as an atomic demolition munition version), the W18, and the W23. Already under development were some nine warhead applications projects, as well as the B12, B18, and B20 implosion bombs and the B11 gun-type bomb.

In 1954, when the AEC completed the conversion of an Army ordnance plant at Amarillo, Texas into the Pantex nuclear weapons assembly facility, some experienced weapon assemblers from Sandia transferred to the new facility. Sandia later opened a weapon evaluation office at Pantex, managed successively by Dennis Murphy, Wilbert Sherman, Leonard Parsons, James Martin, and Oscar Hernandez. This suboffice of about two dozen Sandians had heavy responsibilities for evaluating the continuing quality of the national stockpile.

During the Quarles administration, new weapon design concepts and the need to make war reserve thermonuclear bombs for the national stockpile meant continued growth. Implementation of these new concepts had scarcely begun before President Eisenhower called Quarles to Washington in August 1953 to serve as Assistant Secretary of Defense for Research and Development. From 1955-1957 he served as Secretary of the Air Force, and from 1957-1959 was Deputy Secretary of Defense. He died of a heart attack in 1959 on the day President Eisenhower intended to appoint him Secretary of Defense.

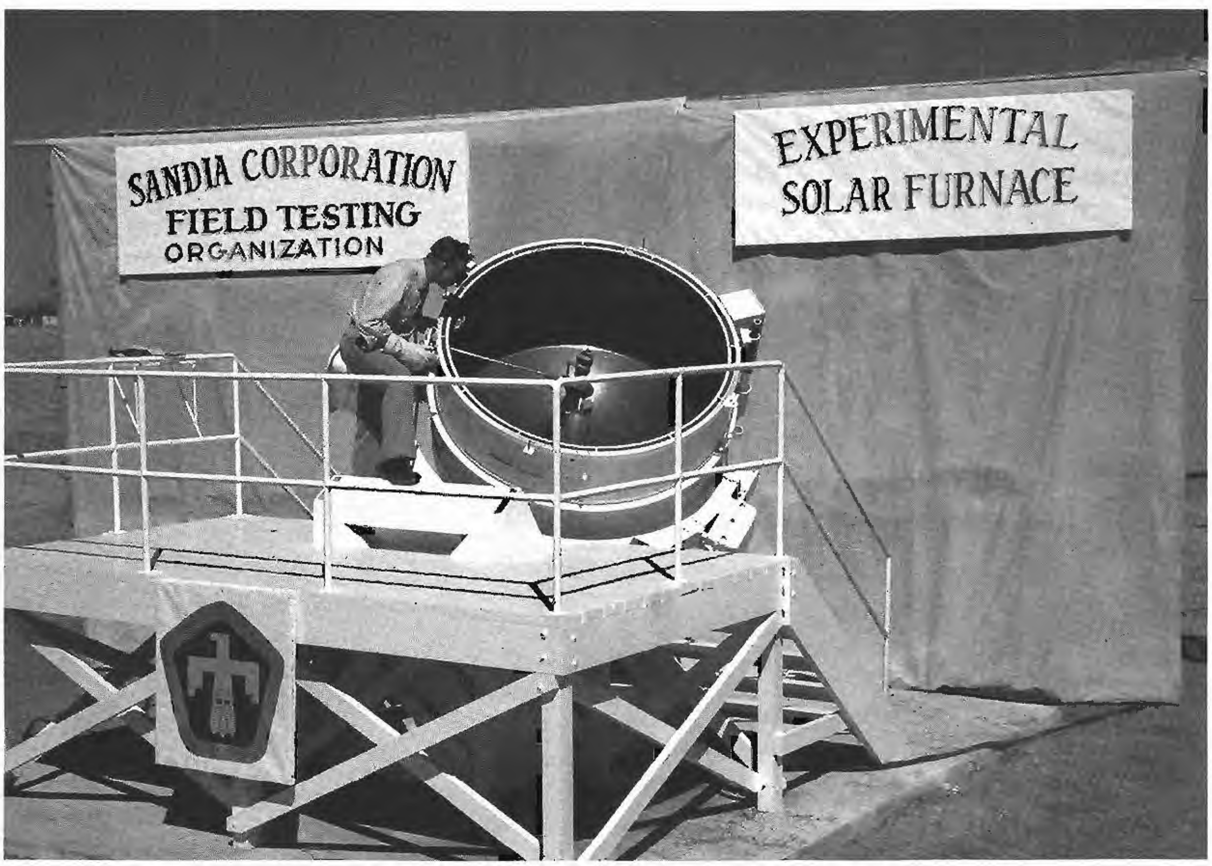
James McRae meets with AEC officials in 1957. *Clockwise from bottom left:* General Alfred Dodd Starbird, McRae, Max Howarth, retired General Kenner Hertford, General Kenneth Fields.

MCRAE LEADERSHIP

James McRae, a native of Vancouver, British Columbia, succeeded Quarles in September 1953. In 1937, after earning graduate degrees at the California Institute of Technology, McRae joined Bell Laboratories and during World War II became a colonel in the Army Signal Corps. He received medals for leadership in the development of electronic countermeasures to jam enemy radar for the protection of Allied aircraft. He had charge of systems development at Bell Laboratories in 1953 when he was reassigned to Sandia. With his people-oriented management style, McRae provided leadership during Sandia's implementation of new concepts in nuclear weapons design.

McRae's career at Sandia had an inauspicious beginning. Arriving in a hurry to replace Quarles, he neglected paying a courtesy call on New Mexico Senator Clinton Anderson. Later, when McRae first testified before a congressional committee, Senator Anderson greeted him with the observation that someone taking charge of several thousand employees in the hometown of a member of the Joint Committee on Atomic Energy should at least drop by to say, "How do you do." Anderson was very influential and McRae soon mended this fence.

McRae continued the management pattern begun by Quarles, with a Bell Laboratories engineer at Sandia's helm and a Western Electric leader as its general manager. McRae's first general manager was Max Howarth, followed in 1957 by Siegmund "Monk" Schwartz. This informal custom extended to other corporate positions: Bell Laboratories scientists served as directors of research, Western Electric executives as directors of purchasing, and so forth. Because these executives usually served only a few years before returning to their home corporations, less transient Sandians described them as "visitors from the East."



Sandia's first venture into solar energy came in 1956 when it converted a surplus army searchlight into a solar furnace for heat-testing materials.

NOVEL APPLICATIONS

Sandia's engineers were alert to the potentials of many advances made outside the Laboratory. For example, the plastics, microwaves, and digital computers that fascinated Americans during the 1950s interested Sandia engineers and scientists as well.

Hoping to use plastics to reduce weapon weight, Sandia opened a laboratory during the early 1950s under the leadership of Leland Sangster, better known outside Sandia as a magician. He had worked vaudeville with Jack Benny and gained fame by driving automobiles while blindfolded. His plastics laboratory experimented with encasing electrical and electronic weapon parts in plastic resins to protect them against impact, shocks, and moisture.

In 1956 Sandia went on to open a plastics shop under Harold Payne to explore substituting high-strength and lightweight plastic composites for metal parts. To heat-weld various plastics together, this shop acquired microwave ovens, then a novelty. After using them, Payne and his associates predicted that microwave ovens would eventually find applications in every home kitchen, predicting that they could "bake a cake in a minute." The use of microwave technologies in radar and communications became the applications of greater significance at Sandia.

Computing was in its infancy during the 1950s, and Sandia had none of the huge mainframe computers designed for weapon development during World War II. At first, Sandia rented card-programmed calculators from International Business Machines (IBM), and by 1954 it had three of these vacuum-tube machines, more than any other laboratory in the nation. Henry Schutzberger headed the division that operated them, using stacks of keypunch cards to perform basic arithmetic functions. Schutzberger asserted that these machines could do in a minute calculations, such as bomb trajectory tables, that took a mathematician with a calculator eight hours to perform.

In 1959, this IBM 705 mainframe computer with its magnetic tape recorders filled an entire room in Sandia's building 880.

In addition to card machines, during the 1950s Sandians used smaller analog computers for many applications, sometimes designing such computers to fit specific needs. Howard "Jim" Durham, for example, built a computer he named Raypac (ray path analog computer) to support weapon effects analysis.

In 1954, Sandia acquired its first digital computer, a CRC 102, soon followed by an IBM 604, Elecom 125, CDC 3600, and IBM 7090. It opened computer centers operating around the clock, seven days a week, to keep up with demand for calculations. "One suspects that the present methods of defining a technical design by drawings and specifications probably are obsolete," Glenn Fowler predicted. "The day is not far off when information stored in written form on pieces of paper will be considered essentially useless compared to information stored in some form amenable to automatic handling by electronic methods." Fowler's prediction proved generally accurate, and Sandia continued to advance its computational capabilities into the 1990s, when it became a world leader by achieving massively parallel computer speed records.

Sandia's location in the Southwest inspired some early experimentation with solar energy. Taking advantage of abundant sunshine, in 1956 John Eckhart and Carroll Coonce converted an Army surplus searchlight into a solar furnace for heat-testing materials. Installed on a tracker pointing it toward the sun, the searchlight mirror focused sunlight to generate temperatures capable of melting materials of interest. It served so well compared to other energy sources that Sandia installed a permanent solar furnace.

Plastics, microwave circuits, computers, and solar energy applications all grew from Sandia's sole function during the 1950s: nuclear weapon engineering. Of the many advances made in weapon design during the decade, Sandians later took great pride in three particular concepts: "wooden," "building-block," and "laydown" bombs.

Encapsulating, or "potting," telemetry and weapon components in plastic resins protected them against shock and moisture.

WOODEN BOMBS

Weapons designed by Sandia and Los Alamos and produced for the military in the late 1940s and early 1950s incorporated many commercial components adapted for use in arming, fuzing, and firing systems. Liquid electrolyte batteries and electromagnetic relays are examples. To check on the operational status of these weapons, military organizations had to use large amounts of monitoring equipment and many highly trained personnel. Batteries also had to be periodically recharged. The military services wanted to reduce the need for continually testing and monitoring the weapon components and circuits and, at the same time, they wanted new weapons to be smaller, lighter, more versatile (e.g., with a full-fuzing option including strategic airburst, laydown delay burst, and contact burst upon hitting a target), more rugged (e.g., bomb "laydown" capability), more reliable, and able to stay in dormant stockpile for a longer time.

In early designs, nuclear weapon maintenance resembled that for aircraft on standby — planes were regularly taken out of storage, tested, and the engines started. Arthur Machen and his liaison office trained servicemen to perform maintenance testing, and Sandia assigned personnel to assist each weapons storage site. In addition to sending personnel, Sandia designed the sophisticated and expensive testing equipment needed at each site. Moreover, experience revealed that the testing process could itself produce defects in components. In brief, maintenance proved costly in equipment, personnel, reliability, and readiness. The military services were anxious to reduce these, especially the time needed to ready a weapon, and Sandia shared their concerns.

Recognizing all of these desires, Sheldon Dike and Walter Wood of Sandia's systems analysis group articulated the "wooden bomb" concept. The goal was not only to design and produce weapons that minimized the necessity for military personnel to test and monitor weapons during stockpile storage, but also to meet the new array of stringent military characteristics. The wooden bomb would be a nuclear weapon that would lie in storage for twenty or more years without major maintenance, yet could be pulled from the stockpile and used at a moment's notice. Bob Peurifoy noted the concept was "scary, like parking your car in a garage for years and expecting it to start when you first turn the key."

A further impetus came from a report by George Edwards of Bell Laboratories, employed by James McRae as a quality control consultant. Edwards visited storage sites in early 1954 and told McRae that, before weapons could be used, the detonators and cables had to be installed and correctly connected, various components had to be installed, the batteries charged, and the fins bolted on. "One doesn't expect his automobile to be delivered to him," Edwards said, "with the fenders separate to be bolted on when he gets ready to drive it." Clearly, Edwards reported, Sandia should strive for improved readiness capabilities.

ZIPPERS

In the early nuclear weapon designs, an initiator inside the pit released a neutron burst to initiate the chain reaction. Weapon maintenance included frequent replacement of these limited-life internal initiators, which required extensive disassembly. As an alternative to initiators, Los Alamos in the early 1950s conceived of using a miniature betatron to accelerate electrons into a beryllium target as a neutron generator that could be installed outside the pit, easing the regular replacement maintenance. Almost in parallel, a small electronic device, using tritium ions accelerated onto deuterium to produce neutrons, was conceived at the University of California at Berkeley. At the request of Los Alamos, Sandia undertook the engineering development of both devices and contracted with the General Electric Research Laboratory at Schenectady for a program of development that resulted in selecting the electronic neutron source for first application.

Zipper was selected as a code name for the classified device by the Zipper Steering Committee after it was allocated the letter Z following the use of x-unit for weapon firing sets. The Zipper Steering Committee was composed of representatives from Los Alamos, Sandia, the University of California at Berkeley, and later from Lawrence Livermore Laboratory. Glenn Fowler, director of electronics, somewhat facetiously indicated that the word Zipper referred to their ease of replacement: their location external to the pit and high explosive assembly made it possible to open the side of a weapon, replace the neutron source, and "zip it back up." No longer was it necessary to return the nuclear systems to their production site for disassembly and initiator replacement.

Sandia's Zipper investigations began in Building 802, upstairs from James McRae's office, and he often stopped in to see the work of Wesley Carnahan, Ted Church, and the team testing a 235-pound betatron and later the 20-pound experimental neutron source. McRae took a personal interest in the safety of their work with high voltage and encouraged them to seek ruggedness and ease of manufacture in their designs. In 1955 he approved the arrangements for neutron generator development support by the General Electric x-ray department.

The AEC handed Sandia the task of getting these neutron generators into production. Sandians went to Florida in 1956 to assist with the design of production facilities at the new Pinellas Peninsula Plant built by General Electric for Sandia. After the building was finished, the AEC decided that it should own it and manage production contracts directly. Sandia managed the plant during its first months of operation until the AEC completed negotiations on its contract with General Electric, making Pinellas part of the AEC production complex.

Development of an external neutron source aided the AEC laboratories in their quest for weapons that were maintenance-free, requiring no disassembly. And while pursuing this goal, Sandians achieved advances in the designs for fuzes, batteries, and "one-shot" transducers.

Working with the electronics in a field test trailer at Nevada Test Site in 1953 are Norman Bolinger, *foreground*, Bob Witthauer, and Ed Ames.

ONE-SHOT COMPONENTS

The nuclear physics package in each weapon is a one-shot device: once it has exploded, its job is done. Arming, fuzing, and firing components that didn't have to be tested by military personnel could be one-shot devices, too. To stretch an analogy, safety airbags in modern automobiles are essentially one-shot devices, are not reusable, and estimates of their reliability must be accomplished statistically rather than individually. Thus, active research and development work concentrated on replacing many of the reusable components in arming, fuzing, and firing systems with one-shot devices. By containing small explosive charges and solid chemicals, the components could meet the new needs for smaller size, increased ruggedness, increased reliability, and longer stockpile life.

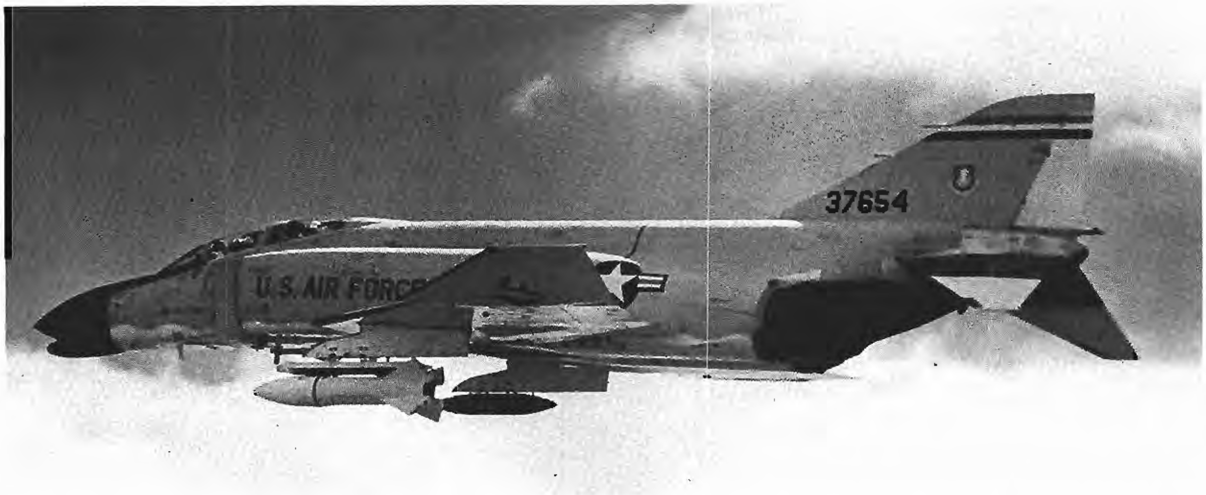
Early weapons used lead-acid batteries. Some follow-on weapons used nickel-cadmium batteries. Both types of batteries required frequent charging and contained liquid electrolytes that were corrosive. To develop batteries for wooden bombs, James McRae in 1953 formed a power supply division to initiate research in battery technology. Chuck Burrell, Charlie Bild, and Bob Wehrle found a solution in the one-shot thermal batteries originally developed in Germany. Their work was supported by fundamental investigations by Sandia's first physical chemist, Frank Hudson. Containing no liquid, these solid, rugged batteries would not deteriorate for many years and never required charging. An electrical or mechanical input to a thermal battery ignited a dry chemical inside, and its heat melted the other powdered chemicals within, forming an electrolyte and generating either a high or low voltage to power a weapon firing set for a limited time. Because thermal batteries could not be tested individually before use, several taken at random from each production lot were ignited in simulated use-environments to statistically estimate the reliability of the rest of the batteries in that production lot. More than ninety-nine percent of all the batteries tested performed as designed. Thus began Sandia's power supply research that steadily improved thermal and other type batteries, eventually earning Sandia national recognition as a leader in battery research and development.

Electromagnetic relays used in arming, fuzing, and firing systems in early weapons were adapted from telephone-type relays. Although these relays met the requirements at the time, they did not meet the more stringent requirements for use in wooden bombs having full-fuzing options, particularly the need for increased reliability, smaller size, and ruggedness. Sandia's relay and switch development group initiated the adaptation of a small and rugged one-shot explosive switch developed by the Naval Ordnance Laboratory. When triggered by a small pulse of electrical energy, a tiny explosive charge produced a gas, which quickly pushed a piston carrying a cylindrical contact that opened one pair of electrical contacts and closed another pair. Universal Match Corporation set up a manufacturing plant to produce the switch in large quantities and their chemists helped Sandians characterize the explosives. With Sandia guidance, Universal Match also established a quality control program to help produce this high-reliability one-shot component. Jay Grear observed that to help assure that the high reliability requirements were met, many thousands of switches were produced in a pre-production run; most of these were test fired in a wide range of simulated normal-use environments with no failures encountered.

In addition to switches, many other one-shot components incorporated explosives: valves, mechanical pistons, and firing sets are examples. For some of the early one-shot explosive devices, development proceeded by the Edisonian cut-and-try method. Sandian Del Olson observed that production of the explosive actuators initially was more art than science, "you need a pinch of this and a stir of that and it worked, and you built thousands and tested hundreds and if the hundreds worked you put the others in the stockpile. We don't like doing that, but it works."

As supervisor of experimental research, Richard Claassen employed many professionals who made their marks at Sandia. Among them were George Anderson and Frank Neilson, who were assigned to analyze firing sets and detonator circuits. Out of their studies came design improvements, notably Neilson's exploration of explosive-to-electric transducers, both ferroelectric and ferromagnetic types. Polarized ceramics used in these devices, when shocked by a small explosive or some other mechanical stress, released the remnant polarization in the form of a high-voltage discharge. Sandia used the discharges from these one-shot devices to initiate weapon components, and it took a leadership role in ferroelectric and ferromagnetic sciences that has continued to the present. Neilson's ferromagnetic breakthrough came "because Frank really understood what was going on," Claassen later asserted. "Other people had failed because they hadn't understood the physics involved."

Claassen also initiated fundamental investigations on piezoelectric crystals that when crushed or mechanically stressed discharged an electric current, and identified one that could serve as a contact fuze. Placed in the nose of a nuclear bomb, a contact fuze using piezoelectric crystals can operate in two modes to produce an electrical output: either by being crushed from one end (potentially unreliable because the electrical wiring may be destroyed first) or, preferably, by responding to ultrasonic energy that travels rapidly along the weapon case from the point of weapon impact to the contact fuze before either the contact fuze or the wiring is damaged. The electrical output closes a switch to initiate the detonation of the nuclear physics package. These one-shot contact fuzes, destroyed during their function, helped Sandia to design nuclear



The first sealed-pit weapon, the W25, was used with the Genie rocket and could be carried beneath aircraft, as shown in this testing picture.

bombs with contact burst as one of their full-fuzing options.

In summary, developing one-shot components for arming, fuzing, and firing systems proved a key to designing wooden bombs that not only eliminated much of the need for military personnel to monitor and test the weapons on a frequent basis but also provided them with smaller, lighter, full-fuzing options and more rugged, more reliable, and longer-lived weapons.

BUILDING-BLOCK CONCEPT: SEALED-PIT WEAPONS

Initially, the capsule containing the fissile material of a nuclear weapon had been kept separate from the rest of the weapon system, to be inserted only when the weapon was used. The first sealed-pit weapons, in which the capsule is sealed hermetically and contained permanently within the pit at the center of the weapon, were introduced in 1957 by Los Alamos. The sealed pit allowed the physics package to be utilized as an interchangeable building-block component that could be readily used in different weapon systems.

By the late 1950s, Sandia, with AEC concurrence, had begun to abandon the old Mark numbering system to identify design models and to use instead the B designation for bombs and the W for warheads. The W25 and B28 marked another watershed in the history of nuclear weapons. The W25 warhead was designed for use with the air-to-air rocket called Genie. It was a pioneer — the first warhead to be completely designed and to enter the stockpile as a sealed pit/wooden bomb system. The entrance of the B28 to the stockpile marked the flowering of the building-block concept. These, plus the W54 Davy Crockett and the B54 Special Atomic Demolition Munition, merit special attention.

Sandians, led by John Cody, Samuel Moore, and Bill Hoagland, designed the building-block B28 system initially as a fusion-type tactical bomb to replace the Mark 7 for external carriage on fighter-bombers. The bomb project evolved into a basic sealed-pit warhead provided by Los Alamos with both bomb and missile applications. When fitted with kits of various shapes and arming, fuzing, and firing capabilities, bombs capable of both internal and external carriage by a variety of aircraft could be assembled. The B28 therefore became the Air Force's primary bomb for delivery by both tactical and strategic aircraft throughout the 1960s. The Navy also adopted it for aircraft delivery, and the basic B28 warhead found application as the W28 for the Mace tactical missile and the Hound Dog strategic missile. Hence, the

Left to right: Robert Poole, James McRae, Ernest Lawrence, and Edward Teller inspect the launcher for a Davy Crockett weapon in 1958.

William Denison and James Kane inspect three weapon designs. *Top to bottom:* the B57; B43; and Davy Crockett (W54), the small weapon standing on its nose.

B28 became the multipurpose building block for seven weapon systems, resulting in significant savings in design effort and funding.

Walter Treibel, William Wells, and John Piper, together with their Los Alamos counterparts, designed the W25 for use with an air-to-air rocket first called the Ding Dong and later the Genie. It was designed to give Air Force fighters the ability to destroy enemy bomber squadrons. Because of its hermetically sealed pit, maintenance was simple compared to earlier weapons. Instead of banks of testers and a platoon of personnel at storage sites, the W25 required only two testers: one to check the warhead seal and another to test the continuity of the firing circuits. Thus, with the addition of sealed-pit weapons to the stockpile in 1957, Sandia began transferring its field engineering personnel from the storage sites to other assignments.

The small size of the W54 Davy Crockett and the B54 Special Atomic Demolition Munition mark another important trend in weapon ordnance design during the 1950s and early 1960s: miniaturization. Starting with huge bombs weighing as much as twenty tons early in the decade, by the end of the 1950s some nuclear weapons weighed less than 100 pounds, small enough for a single soldier to carry. As work proceeded on the W54 warhead, a Sandia California team managed by Leo Gutierrez conceived the Davy Crockett weapon and designed its propellant and launcher as well. With a recoilless rifle launcher, two soldiers could launch the Davy Crockett nuclear warhead.

Multiple uses were envisioned for this portable weapon system. Its integrated designed included a cover with a combination lock to prevent unauthorized access, a removable section of the firing set, and fuzing components consisting of a dual channel mechanical timer as well as a remote control capability. Weighing about 65 pounds, it could be delivered by one man. Based on it, Treibel managed a team that developed the Special Atomic Demolition Munition, designated B54. These portable demolition weapons would allow Army engineers to blast mountainsides down into passes to stop an enemy advance or to destroy bridges and structures to deny their use to the enemy.

In 1958 the Secretary of the Army declared that this weapon "dwarfs in firepower anything we have ever known in the immediate area of the battle line." James McRae and the Sandia design team received awards from the Army for their contributions to development of the Davy Crockett, but the weapon's stockpile life was brief. "People said we can't have a couple of guys start a nuclear war, so it was removed quickly from the stockpile," Gutierrez later philosophized, concluding, "they were probably right."

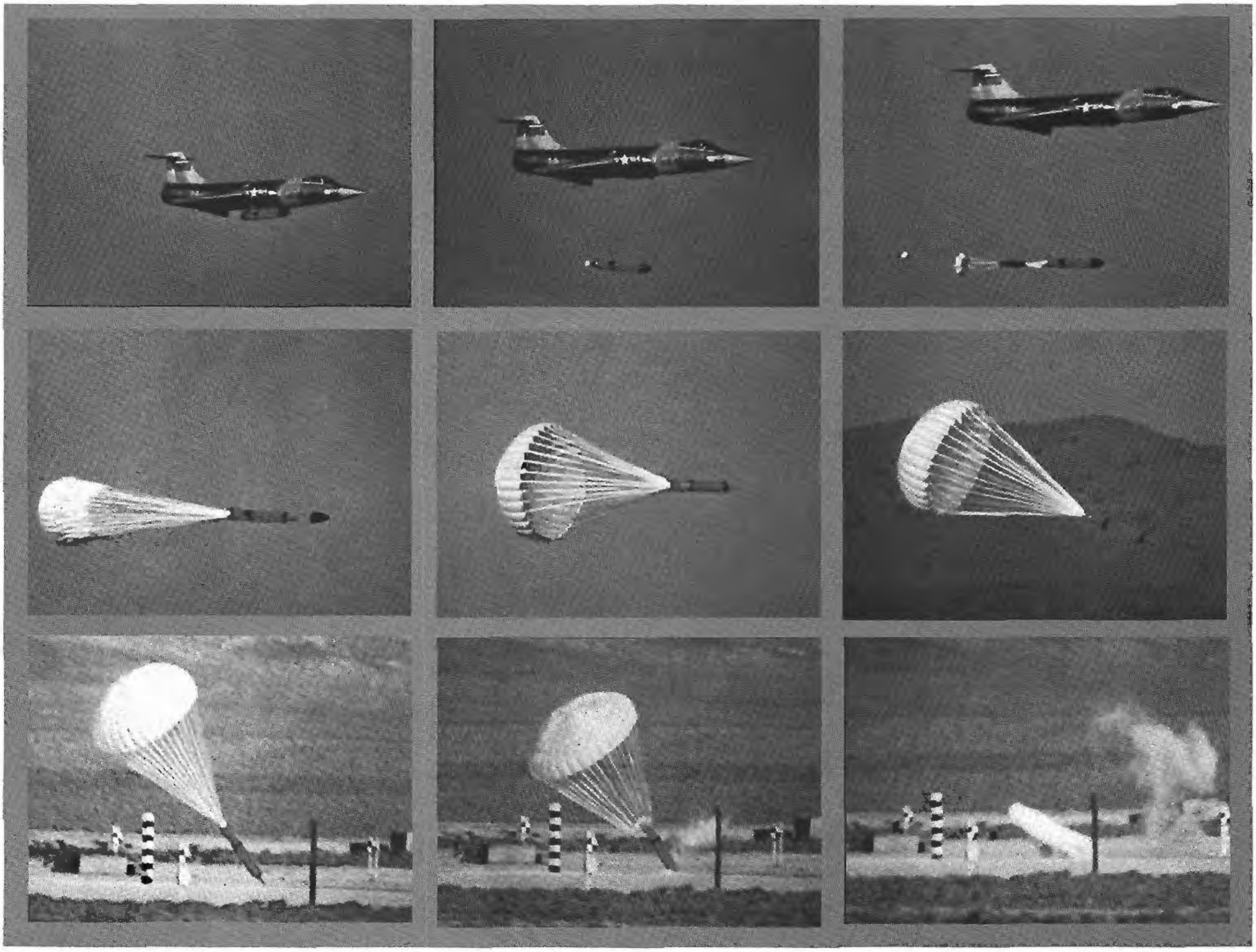
LAYDOWN AND WAIT

By 1954, both the United States and the Soviet Union had jet aircraft capable of high-speed delivery at low altitudes, and both were building elaborate radar systems for early detection of air attacks. Bell

Sandia vice presidents Eaton Draper and Glenn Fowler, and Alan Pope, director of aerodynamic projects, examine a parachute used in a test drop.

Laboratories, for example, played a major role in developing radar defenses and participated in design of the Distant Early Warning radar line across North America. Increasingly, radar, antiaircraft ordnance, and nuclear-tipped missiles threatened the high-altitude delivery mode for nuclear weapons, and defense planners explored alternative delivery methods.

After analysis of this delivery-mode challenge, members of Sandia's experimental weapons research group, notably Kenneth Erickson and Dick Claassen, developed the laydown concept. A jet aircraft flying near the speed of sound (Mach 1) just a few hundred feet off the ground might well elude radar detection until it was too late for enemy air defenses to respond. If it delivered a nuclear bomb at low altitude, however, the blast would destroy the aircraft and crew before they could escape. What the Air Force and Navy seemed to need was a bomb that could fall to the ground and await the escape of the aircraft before exploding. In late 1955, based



Serial photographs of a TX-43 laydown bomb test drop. Note the nose cone coming off to expose the spike on the bomb's nose.

upon Sandia's exploratory studies, the Department of Defense specifically proposed a joint AEC-DoD study and the Tableleg Committee was formed.

In its feasibility report, the Tableleg Committee suggested two possible delivery methods. First, an elaborate aircraft maneuver might provide escape time: as it approached, a low-flying aircraft could pull up and lob its bomb in an arc toward the target, while the pilot looped the plane over and back toward safety. This maneuver would require considerable pilot fortitude in 1950s-vintage aircraft traveling at or above the speed of sound. Second, parachutes, rotochutes, or retro-rockets on a bomb might retard its descent to the ground, slowing it to prevent its destruction at impact, thereby allowing a timer to delay detonation. The second option seemed preferable. But where were bomb designers going to find a parachute capable of retarding a bomb weighing several tons released from a plane at 700 miles per hour at very low altitude?

The parachute problem constituted just one part of the laydown design challenge. Even if Sandia could find a parachute that would reduce bomb descent velocity to less than a hundred feet per second, some means of mitigating the impact shock still had to be found. Moreover, all parts of the weapon had to be "ruggedized" to withstand a hard landing, perhaps on the concrete of an airfield runway. The problem resembled smashing an automobile traveling at fifty miles per hour into a concrete wall and expecting the clock, radio, and starting system to function normally.

Solving the parachute problem fell initially to George Hansche, who had been studying bomb ballistics at Sandia with the assistance of military officers. Hansche recruited aerodynamics experts for the task, including Alan Pope and Randy Maydew, who together formed the nucleus of Sandia's aerodynamics department. These Sandians consulted Air Force parachute experts, notably German pioneers in parachute design brought to America after the war. The Sandians soon recognized that off-the-shelf parachutes would not serve. Their problem demanded substantial research and testing.

Aerodynamic research required wind tunnel testing to assess bomb, shell, rocket, missile, and reentry vehicle aerodynamics, and weapon ballistics. Initially, Sandia rented military and industrial wind tunnels, but in 1956 the Lab built its own wind tunnel to test scale models at transonic speeds. Later, Maydew, Carl Peterson, and Don McBride upgraded the transonic wind tunnel to supersonic and built a hypersonic tunnel with an 18-inch-diameter test section for rocket and missile testing.

For field testing, Sandia built a test vehicle resembling a bomb, and optical expert Ben Benjamin mounted cameras on its afterbody to photograph the deployment of various parachute designs. Using these cameras, photographs of high-speed parachute deployment became possible, revealing the rips, line entanglement, and other complications that interfered with operations. Maydew, in cooperation with the Air Force Parachute Branch at Wright-Patterson Air

At a Sandia hypersonic wind tunnel for aerodynamic research, a Sandia specialist peers through a window to observe the performance of a model.

Force Base in Ohio, designed new ribbon parachutes and conducted thirty-three low-altitude drop tests at Mach numbers from 0.6 to 1.0 from October 1955 to July 1956. These tests conclusively demonstrated that a laydown bomb was feasible and Maydew served as a parachute technical consultant on the Tableleg Committee.

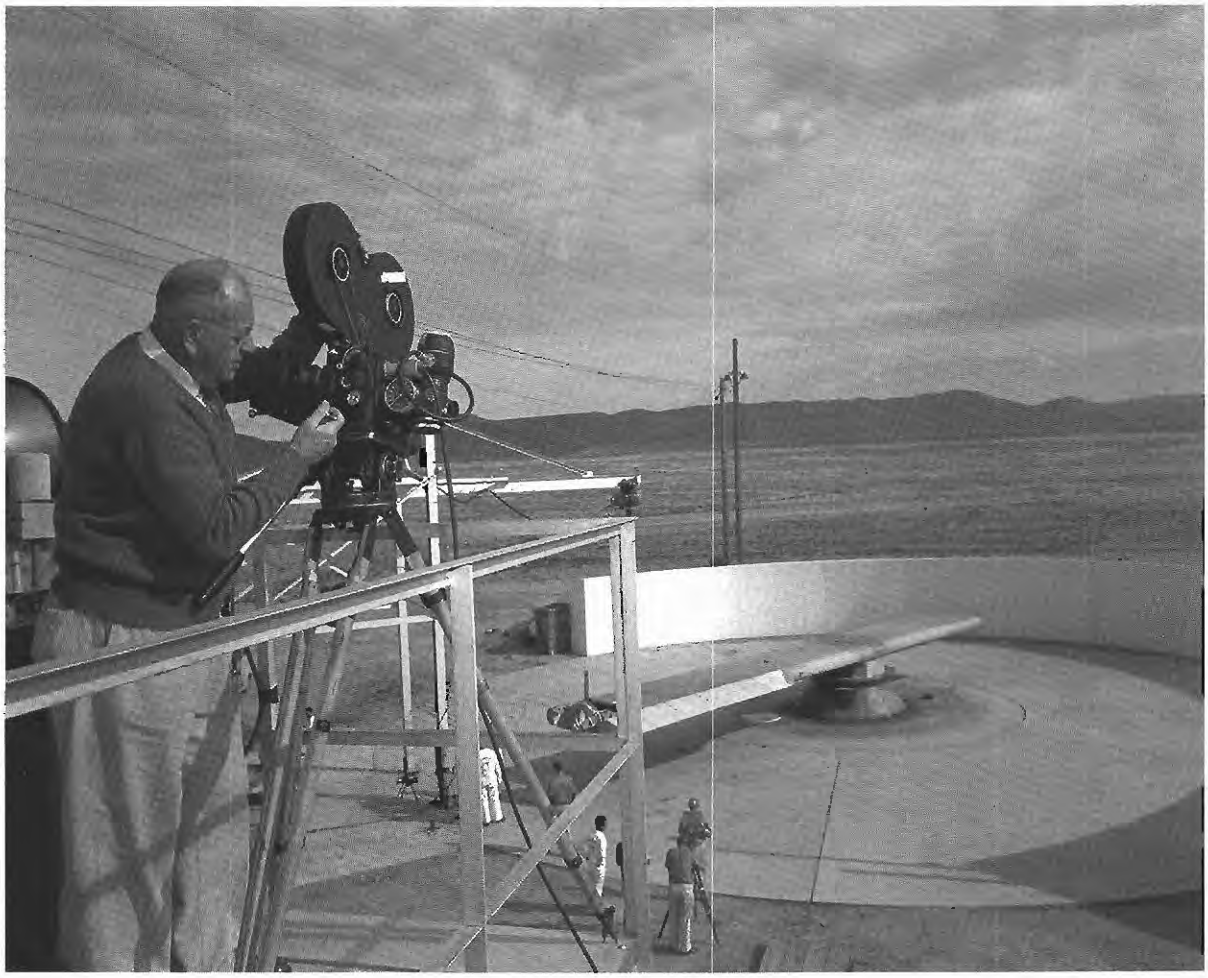
With photography, wind tunnels, computer modeling, and other technology, Sandia's aerodynamic experts and parachute laboratory developed new parachute designs. They also identified new materials, nylon and kevlar, that were sufficiently strong to slow bomb descent to achieve the laydown goal of less than 100-feet-per-second at impact. In a few years, under the direction of Maydew and Peterson, Sandia's parachute technology was second to none, and the Air Force and National Aeronautics and Space Administration began requesting Sandia's assistance with specific parachute designs — for the recovery of space shuttle boosters, for example.

Even after parachute braking, the laydown bomb would hit its target at about fifty miles per hour and obviously needed a shock mitigator. Sandia's engineers reviewed many concepts. Al Bridges thought of using corn flakes in a bomb's nose to absorb the landing impact, and someone else suggested using old computer paper, an idea that seemed so promising that it was tested. Another idea, called the "Lonestar project," involved placing the bomb, surrounded by crushable metal honeycomb in a scow-shaped container resembling a Lonestar fishing boat and dropping it to land flat on a target. Metal honeycomb, as the name implies, had the hexagonal shape and strength of natural bee honeycomb and had been used in aircraft designs to absorb impact shocks.

After reviewing many concepts, Sandia's engineers settled on three shock-absorbent systems: a spike, a cookie-cutter, and the honeycomb, each of which they used in various weapons. Don Cotter, who headed a group studying shock mitigation, said, "The problem is, the thing doesn't come down nicely. If there's a wind blowing, it's dropping and traveling and you worry about tumbling." A spike on the weapon's nose allowed it to impale itself in the target to keep it from slapping down. In the cookie cutter design, the nose cone blew off the weapon before impact, exposing a crenellated design that offered a shock-absorbing surface that also dug into the ground to prevent the weapon from tumbling. The aluminum crushable honeycomb was a material placed in the bomb's nose to absorb the shock of a vertical impact.

For acceleration and impact testing in connection with the laydown bombs and

Sandians inspect an experimental bomb shape (TX-43) with a spike on its nose for shock mitigation.



Allen G. Siegler, director of photography for Lookout Mountain Laboratories, led the crew filming the installation of Sandia's first large centrifuge built during the 1950s for acceleration spin testing.

other weapon designs, Sandia in 1954 opened environmental testing facilities in Technical Area III. Here, Sandia built rocket sled tracks to smash weapons into walls at high speeds, centrifuges to spin weapon parts at great acceleration, and compressed air guns for impact testing. In 1956, it added a 300-foot tower to drop-test bombs and other items. With facilities added to check the effects of temperature variations, vibrations, and essentially all environmental stresses that might affect a weapon, Technical Area III became one of the nation's largest and most versatile test sites. Glenn Fowler said, "We must provide a vehicle which is as simple and reliable as possible under the wide range of environmental conditions to which the vehicle may be subjected in the course of its military handling and use."

The first shock-absorbing device adopted was the cookie cutter with a simple blunt spike on the nose of the W34/Mk 105 Hotpoint. Growing out of the W34 designed for the Navy's Lulu depth bomb and as the warhead for the Astor nuclear torpedo, Hotpoint was envisioned as a lightweight bomb to fill the Navy's need for a weapon with laydown capabilities.

The first weapon to use the long nose spike was the B43. If parachutes held the B43 near enough to a vertical landing, its nose spike impaled the target, holding the bomb upright to prevent slapdown or tumbling. As Cotter observed after seeing the spike system tested, the spike went "chung" right through several inches of concrete and held the bomb there without tumbling until its timer finished ticking. The B43 entered full

At Sandia's new sled track in 1954, preparations are made for a rocket-propelled sled impact test. The Sandians at work are, *left to right*, Walter Drake, Donald McCoy, Fred Brown, and Sid Cook.

Sandia tested its component designs for all environmental stresses including subzero temperatures in cold chambers.

engineering development in 1958, and thereafter the design of every large bomb in the stockpile allowed laydown delivery by parachute if tactics made that desirable. The B43 remained the sole bomb with the nose spike, however. Later designs used crushable honeycomb and shock absorbers.

SANDIA IN CALIFORNIA

In 1952, the AEC created a second nuclear explosive design laboratory at Livermore, California, to compete with Los Alamos in physics package design. Not all of the AEC commissioners wanted it there. Commissioner Thomas Murray, for example, wanted it built at Sandia in Albuquerque, while Willard Libby preferred Reno, Nevada. Ernest Lawrence, Nobel laureate at the University of California, was enormously persuasive, however, and the new laboratory was built in Livermore as an extension of his University of California Radiation Laboratory. Herbert York, one of Lawrence's postdoctoral students at Berkeley, was the Livermore lab's first director. After Lawrence's death in 1958, the facility was renamed Lawrence Livermore Laboratory.

Located in the rolling hills midway between the coast and the San Joaquin Valley, and about fifty miles east of San Francisco, the Livermore community had served as a railroad center for a vineyard region before it became home to a Naval air station during World War II. Surplus facilities left from the air station provided housing for the new AEC facilities before more permanent structures were completed.

In 1952, Bob Henderson, Richard Bice, and Ralph Wilson met with York to negotiate Sandia's role. Even before constructing a separate facility of its own in California in 1956, Sandia provided Lawrence Livermore with vital support, especially with full-scale

Sandians working in the drafting room at Livermore in 1958 before permanent buildings were completed.

nuclear tests in the Pacific and at the Nevada Test Site. Edward Teller, Mervin Kelly, and General Alfred Dodd Starbird visited Sandia in the summer of 1955 to discuss how Sandia should provide continuing support to Lawrence Livermore. In August, Sandia vice president Robert Poole proposed the formation of a laboratory consisting of perhaps 250 employees at Livermore, and McRae broached the idea with the AEC and the Sandia corporate board. With their approval, during the fall of 1955 a few Sandians went to California on temporary assignment to work directly with Lawrence Livermore on its early nuclear weapons — the B27 and its counterpart for the Regulus guided missile, the W27.

Near the end of 1955, AEC Chairman Lewis Strauss told Kelly that Sandia must provide the ordnance engineering support for Lawrence Livermore, and it should not be overly conservative in the personnel and facilities assigned to the task. York also urged that Sandia send more than the 250 employees planned for California assignments. The AEC considered assigning the engineering at Livermore to such firms as Westinghouse and Precision Engineering, but in early 1956 directed Sandia Corporation to establish a laboratory at Livermore under the existing contract. Sandia executive Jack Howard later attributed the formation of Sandia California to strong personal support from York, who wanted a separate engineering organization.

Left to right: Edward Teller, Ernest Lawrence, Donald Cooksey, Robert Poole, Herbert York.

These were among the Sandians sent to Livermore in 1955-56. (1) Charles Barncord, (2) Charles Gump, (3) Clifford Erickson, (4) Benjamin Fisher, (5) Robert Siglock, (6) Gayle Cain, (7) Vernon Field, (8) Charles Winter, (9) Wayne Grimshaw, (10) Frank Thomas, (11) Orval Wallen, (12) James McMinn, (13) Mary Van Brocklin, (14) William Marsh, (15) Nora Byrd.

In early 1956 Sandians from Albuquerque transferred to Livermore, where they first occupied the abandoned naval air station barracks. Howard became the first manager of Sandia's engineering department at Livermore, with Ray Brin and Charles Barncord managing the two project divisions. These and about two dozen personnel officially opened Sandia California at Livermore on March 8, 1956. Two months later, Sandia's manufacturing engineering group opened a west coast division in Beverly Hills to interpret specifications and assist with quality control for suppliers working under new contracts with Sandia. By the end of 1956, Sandia had completed plans to increase its staff at Livermore to about 1,000 personnel and to invest $5 million in the construction of permanent buildings and support facilities.

Called "Cactus Jack" by his friends, Jack Howard thought the key motivation at the new Sandia facility should be competition. Located across the street from Lawrence Livermore, which sought to make its reputation with bold and innovative designs, Sandia California also aimed for technical excellence. Before transferring to Livermore, for example, Howard had never seen a firing set smaller than 134 pounds. At an early meeting, York told Howard that his laboratory planned to design a 50-pound warhead and asked how much the fireset would weigh. Although thinking it might be 100 pounds, Howard said that Sandia would reduce the weight to 10 pounds. On this and related challenges, Sandia delivered.

Sandians occupied building 911, their first permanent building, at Livermore in October 1957; and in November, Robert Poole, vice president of development, transferred to Livermore to manage Sandia's work there. Poole had just completed a tour with Teller and Lawrence to the Sixth Fleet in the Mediterranean to assess Navy operational requirements. At the time, the Navy, Lawrence Livermore, and Sandia had the Regulus missile with its W27 warhead under development. The Navy also had initiated the Polaris submarine missile program, the third leg of the national defense triad:

Vice-president Robert E. Poole consults with department managers Jack Howard and Charlie Campbell at Sandia's California site.

strategic aircraft, intercontinental missiles, and submarine-based missiles.

Among the early projects at Sandia California were contributions to all three pillars of the defense triad. Among these were the W38 for Titan missiles, the B41 bomb for the Strategic Air Command, and the W47 for the Polaris submarine. Key technologies devised during the early years at Sandia California included ferromagnetic firing sets, miniature gas valves, and new instrumentation for weapons testing. Sandia California teams developed small ferromagnetic firing sets for warheads, enabling Sandia to achieve the 10-pound goal. Harvey Pouliot led a group devising tiny gas valves, and he patented an explosively actuated valve. During testing of the W47 for Polaris missiles, Lee Hollingsworth directed a Livermore team that designed telemetry instrumentation to record and assess warhead performance during realistic flight tests. These and related efforts brought Sandians at Livermore commendations from Admiral Raborn of the Polaris program and an enviable reputation for innovative design.

Because Sandia's operations in Albuquerque remained several times larger than in California, Lawrence Livermore's managers expressed concern that the needs of Los Alamos received greater attention, and they pressed for Sandia's expansion in California. Yet, one Lawrence Livermore manager admitted, "Sandia gave the impression they were always looking for more work. They would come up with plenty of manpower to work on these problems, and seemed to enjoy them." Responding to its growing missions, Sandia more than doubled its California site area, added environmental and explosives testing areas, and substantially increased its structural facilities, but the number of Sandians at the site remained fixed at near 1,000. Sandia New Mexico was tasked to provide major component and other support to Sandia California in order to balance out the Los Alamos and Lawrence Livermore support.

HANDLING SAFETY DEVICES

When Donald Quarles, as Secretary of the Air Force, was briefed on the W25/Genie rocket system design, he had concerns about the level of nuclear weapon safety. In earlier weapons, the capsule of fissionable material had been stored separately from the explosive system, presenting no danger of accidental nuclear detonation until the capsule was inserted after takeoff. Now that the W25 pit was sealed inside the weapon, Quarles asked what had been done to guarantee safety.

A DoD group, led by Navy Captain William Klee and known as the Klee Committee, was established to examine the safety issues Quarles and others had raised about sealed-pit weapons. Sandia's response to the concern was to redesign and retrofit the electrical subsystems for the warheads intended for use in fourteen weapon systems. The modifications incorporated new safety features, including a crew-activated ready-safe switch.

As the implications of the sealed pit innovation were examined further, concern was also raised about inadvertent application of power to the weapon while it was being handled on the ground. Sandia's solution was a family of handling safety devices, designed to prevent electrical signals from reaching the warhead connector unintentionally. For bombs and warheads, devices were developed that would block power until they sensed differential altitude, velocity, and/or launch acceleration. Since none of these environments applied to atomic demolition munitions like the B54 that had no trajectory or environment to sense, specialized locking devices were developed and advanced development was initiated on pulse-train switches, early precursors to modern use-control devices.

The first trajectory sensors, commonly referred to as environmental sensing devices (ESDs), were relatively large, originally designed to detect parachute deployment in bombs. These were adapted for use in the W49 warhead used in Atlas, Thor, and Jupiter missiles. However, because it was preferred that the stockpile have a single device compatible with all the warhead programs and because these devices were relatively large, an inertial switch, jokingly referred to by some as the first "goofproofer," was developed. This switch consisted of a tiny piston enclosed so tightly in a cylinder that it could not move far enough until the rocket or missile carrying it attained high acceleration and/or deceleration and sustained it. Just as a jackrabbit start in an automobile forces its passengers back against their seats, the rocket acceleration forced the piston down its cylinder to close electrical contacts and arm the warhead.

Reflecting the tension inherent in trying to meet the requirements of both weapon safety and operational readiness, the military services at first objected to the addition of the ESDs because they considered them contrary to the division of labor specified in the 1953 AEC-DoD agreement regarding missiles and rockets. However, safety concerns prevailed and the devices were installed.

Inertial switch design required extremely close machining tolerances to allow proper metering of the air; that is, the piston could not slide through its cylinder until it sensed the specified acceleration. The millionths-of-an-inch clearance between the piston and its cylinder pushed the envelope of the machining art, and Sandia formed its first production task force to join with the production contractor's engineers in advancing the technology. Sandia tested the switches in centrifuges spun with rockets to achieve acceleration. Robert Stromberg took one to Cape Canaveral for testing and installed it on the NASA rocket system that propelled monkeys into orbit in preparation for John Glenn's Mercury flight. Douglas Ballard, known to the public as an artist rather than as an engineer, headed the Sandia task force that successfully produced an inertial switch that achieved ninety-nine percent reliability over a production run of several thousand units.

THE SPUTNIK SHOCK

Coupled with Soviet development of fusion weapons, the steady electronic transmission from the Soviet Sputnik orbiting the earth in 1957 shocked the United States, especially its scientists and military leaders. Apparently, the Soviets had achieved the capability to launch ballistic missiles. James McRae pointed out that prior to 1957 the United States, with strategic bombers and "those watermelons that the Watermelon Corporation helps to design," had a massive retaliation capability the Soviets lacked. With its Sputnik success, the Soviet Union was on its way toward a similar capability.

In response to the chill of Sputnik, the Strategic Air Command dispersed its bombers and maintained a status of "quick reaction alert." Schedules for deployment of the Atlas and Titan intercontinental-range ballistic missiles, the Jupiter and Thor intermediate-range missiles, and the submarine-launched Polaris missiles moved ahead on a crash basis.

For Sandia, the most immediate technological challenge was development of the W49 thermonuclear warhead for the missiles on a 10-month time-scale. This system, which remained in the stockpile for 17 years with a zero failure record, was developed under the full set of weaponization criteria with no limits placed on its operational capabilities. Because of

Dan Parsons, Dale Fastle, and Ben Benjamin photograph space satellites passing over Sandia.

uncertainties as to the possibility of Soviet countermeasures, particularly nuclear radiation, Sandia designers developed a warhead electrical system that used no components known to be sensitive to credible levels of nuclear radiation. In addition, to enhance nuclear safety a new type of fireset, known as a chopper-converter, replaced the high voltage thermal battery system used in earlier wooden bomb designs.

The W47 for the Polaris submarine-launched ballistic missile system had been authorized for development just before the Sputnik "wake-up call" and this program, too, was accelerated. This system was to be developed by a four-organization team: the Navy was responsible for the arming and fuzing subsystem; Lockheed designed the reentry body; Lawrence Livermore designed the physics package; and Sandia California was responsible for the warhead structure, the boost system, the neutron generator, and the firing subsystem.

President Eisenhower and Congress created the National Aeronautics and Space Administration to fully engage in a space race and reorganized Defense agencies to place added emphasis on research. Herbert York left Lawrence Livermore Laboratory and became the new Director of Defense Research and Engineering, while Roy Johnson headed DoD's new Advanced Research Projects Agency in charge of military satellites and high-risk research. Because these agencies had no laboratories of their own, they were to fund research and development at existing laboratories, Sandia among them, on a reimbursable basis.

During the winter of 1957, Sandians could tune their radios to Sputnik's band and listen to its pulsing signals. Ben Benjamin, Dan Parsons, and a Sandia optical team tracked and photographed Sputnik's passage over Albuquerque. With renewed urgency, Sandia's engineers struggled to meet new deadlines for weapon production, notably the three-year advance in schedule for the Polaris warhead. And, thanks to funding from Defense agencies, Sandia entered military satellite programs and other advanced research initiatives.

These were some of Sandia's women supervisors in 1958. *Seated from left:* Oleta Morris, Winifred Fellows, Evelyn Garman, Wynne Cox, Claudine Sproul. *Standing:* Irene Palmer, Ilva Baldwin, Lila Ness, Beulah Sutherland, Kathleen Sadler, Martha Tuffs, Bertha Allen, Frances Hale, Patricia Farley.

Summarizing the impact of the Soviet Sputnik success on the United States, McRae thought it salutary. "It woke us up, established the feeling that we are in a serious race, that we have to win every contest and so we have gone back to work again," he said. "We are now serious about it, and I personally am glad the Russians beat us out with their first Sputnik."

EDUCATIONAL PROGRAMS

Sandia shared in a national program to enhance science, mathematics, and engineering education that began in response to apparent Soviet advances in those fields. As early as 1945, Sandia's management had cooperated with the University of New Mexico in arranging after-hours education for employees, and during the 1950s had sponsored educational programs for secondary school faculty and students every February 11, Thomas Edison's birthday. In Sputnik's aftermath, Sandia's cooperative educational programs expanded at the university level to include all New Mexico schools plus colleges in Texas and surrounding states. It increased contracting for research at universities as well.

From the employee perspective, the most important educational initiative of the late 1950s emanated from a proposal by Glenn Fowler, chairman of the education committee. Modeled on programs available elsewhere, including Bell Laboratories, the Technical Development Program (TDP) funded postgraduate education for many Sandians. New recruits to Sandia with bachelor's degrees in engineering would take courses at the University of New Mexico while working part-time. Nearly all participants earned master's degrees in the process. The program included courses designed to help the student employees gain specialized knowledge appropriate to Sandia's work.

Sandia's educational programs produced numerous success stories. Ray Powell pointed to Gilbert Cordova as an example. At Sandia, Cordova began work as a custodian, obtained his education, went to the AEC in Washington and then managed the AEC Sandia Office before becoming president of the University of Albuquerque. Art Arenholz listed Dennis Hayes as another example. Hayes, who began his career as a mail clerk, earned a doctorate in physics, and rose to top management at Sandia.

Early Technical Development Program participants Mike Heck, David Putnam, and Tom Feltz at the University of New Mexico.

The TDP and USE Programs

Sandia requires that the members of its technical staff be well-trained and completely up-to-date on developments in their chosen specialties. A variety of educational opportunities have been offered to employees over the years, allowing individuals to hone their skills and broaden their minds.

In the 1950s, the educational standard in the engineering community was a bachelor's degree. Very few engineers chose to stay in school beyond that point and they had little incentive to do so, since most jobs did not require advanced degrees. Sandia tried to hire engineers with advanced degrees in the early 1950s, but they were simply not available. But in the late 1950s, Sandia decided that the specialized nature of its engineering work required more detailed instruction in some areas. Upper management saw a need for individuals capable of taking on research-oriented tasks in order to create more technically sophisticated systems.

In 1959, the Technical Development Program (TDP) was piloted with a small test group. The Sandia Education Committee created a curriculum focusing on analytical engineering methods, nuclear physics, advanced mathematics, and statistical analysis. Recruits with bachelor's degrees in electrical or mechanical engineering would enter the TDP, taking courses at the University of New Mexico (UNM) for two years while working part time at Sandia. In 1960, the course was offered to new recruits for Albuquerque. Livermore implemented a similar program in 1961.

Seventy-five newly minted bachelor's-level graduates in electrical engineering and mechanical engineering joined the first TDP class at UNM in the summer of 1960. Two

Thirty-seven members of the first TDP class were still at Sandia 25 years later. Gathered here are, *front row from left:* Roger Roberts, Bill Sullivan, Jesse Allen, Jim McDowell, Heinz Schmitt. *Second row:* Al Giddings, Ray Krieg, Norb Siska, Arlo Nord, Dennis Mangan. *Third row:* Ralph Wardlaw, Jim Lang, Leo Klamerus, Jon Barnette, John Kane. *Back row:* Cliff Jacobs, Tony Russo, Tom Workman, Dick Braasch, Bob Alvis.

years later 68 of them finished the course — 37 of whom were still at Sandia in 1985. In all, the program trained 406 employees in the nine years it existed. Many of them were later to be found in Sandia management. TDP was phased out as the demand for master's-level degrees became the standard in hiring new engineers — both at Sandia and in American industry in general. Sandia followed the TDP with a series of educational programs, such as the Doctoral Study Program, leading to higher degrees for staff members.

In 1966, then-president Siegmund "Monk" Schwartz recognized that while Sandia was providing many opportunities for staff to maintain its technical vitality, little was available that was appropriate for engineering division supervisors and department managers. To meet this need for continuing education, the Unified Science and Engineering (USE) course was developed and attended by all first- and second-level technical supervisors, about 300 in all, over a period of several years. The course, developed and administered by Orval Jones and Duane Hughes of the Research and Personnel organizations, respectively, covered modern developments in mathematics, science, and engineering, and required full-time participation of 25-30 supervisors for six weeks in a dedicated facility in the Coronado Club. It included 117 lectures by 25 Sandia subject-matter experts. Al Narath, future president of Sandia, gave the solid-state physics lectures. A reference library of 23 technical books was given to each participant.

SYSTEMS ENGINEERING RESEARCH

At the time of the Sputnik launch, the approach to weapons ordnance design at Sandia was in transition. During the early years, each weapon project typically was undertaken by a project group of twelve to twenty people under a project manager with lead electrical and mechanical engineers. Noting this system had resulted in design proliferation, Leon Smith joined with other division supervisors in 1955 to coordinate electrical systems designs among the various project teams. This proved productive, and in 1956 Bob Henderson approved the formation of a department headed by Smith to coordinate electrical systems designs, including firesets, fuzing, critical safety, and, later, command and control — systems engineering as contrasted to project engineering. "We essentially forced some commonality of approach among the various project groups," Smith recalled.

In 1957, then-vice president of research Glenn Fowler took a personal interest in the coordination of advanced research and engineering development and in the establishing of basic research programs to support Sandia's engineering design effort. Frank Hudson and Dick Claassen were campaigning to expand Sandia's fundamental research, and Fowler joined that campaign, securing a hearing on the subject before Mervin Kelly, chairman of Sandia's corporate board. Claassen told Kelly of the need for expanded research. "Don't tell me that; you told me that a year ago," Kelly interrupted. At the end, however, Kelly approved Claassen's proposal, and Claassen ultimately found himself the director of a new research organization.

"Lots went on," said Claassen, recalling early research, "Frank Neilson came up with the quartz gauge for measuring shock pressures in solids ... and others provided some new understanding of stress wave propagation in solids. Fred Vook was interested in radiation effects, so we got the Van de Graaff accelerator, and Fred and his people have followed that line and variations of it ever since. It was the start of our plasma physics work ... Bill Cowan developed compressed magnetic field generators, which still play a role in pulsed power sciences."

Sandia's first gun facilities for shock-compression research were also built in the early 1960s. This work was complemented by the establishment of the static high-pressure laboratory in 1962. Research in these facilities by Bob Graham, Orval Jones, George Samara, Rick Wayne, and others was crucial to the understanding of the shock response of ferroelectric, piezoelectric, and ferromagnetic materials and to the development of a large family of shock-actuated weapon components and diagnostic tools.

Concerned about the effects of high-altitude missile deployment and possible enemy countermeasure explosions, Sandia acquired its first nuclear reactors and accelerators to begin the analysis of radiation effects on weapon designs. Furthermore, during the 1950s the AEC sponsored the development of nuclear-powered aircraft and spacecraft at its laboratories, together with studies of radiation from such nuclear engines and the alterations it caused in materials and components. Nuclear reactors and accelerators thus served multiple research functions.

Dick Claassen and Frank Hudson discuss plans for the fundamental research program at Sandia.

The research group acquired a 2-million-electron-volt Van de Graaff accelerator in 1958 to test the responses of materials to radiation and conduct research in radiation physics and chemistry. This high-energy particle accelerator permitted study of changes in materials produced by single types of charged particles at controlled intensities. With Elmo Hirni operating the new accelerator, Claassen's team used it to examine the effects of electrons and electron-produced gamma rays on semiconductors and plastics, materials that became increasingly significant to Sandia's quest for smaller and lighter weapons.

A nuclear reactor producing radiation from several different particles over wide energy ranges could simulate nuclear weapons effects more closely than Van de Graaff or other particle accelerators then available, and Sandia in 1957 planned a nuclear reactor to foster research into weapons effects and physics. Claassen's research group, the weapon effects group led by Tom Cook and Carter Broyles, and radiation effects teams led by John Colp and Bill Snyder united behind the acquisition of a nuclear reactor, and the AEC approved construction of the Sandia Engineering Reactor Facility — for research, not power production. Snyder managed the design of its pressurized-water-cooled reactor core and associated systems, while Colp investigated the remote handling of materials to protect Sandians against radiation exposure. One solution, a remote-controlled mobile robot, promptly dubbed Sandy Mobot, became Sandia's first venture into robotics, although years would pass before Sandia initiated its major robotics research program.

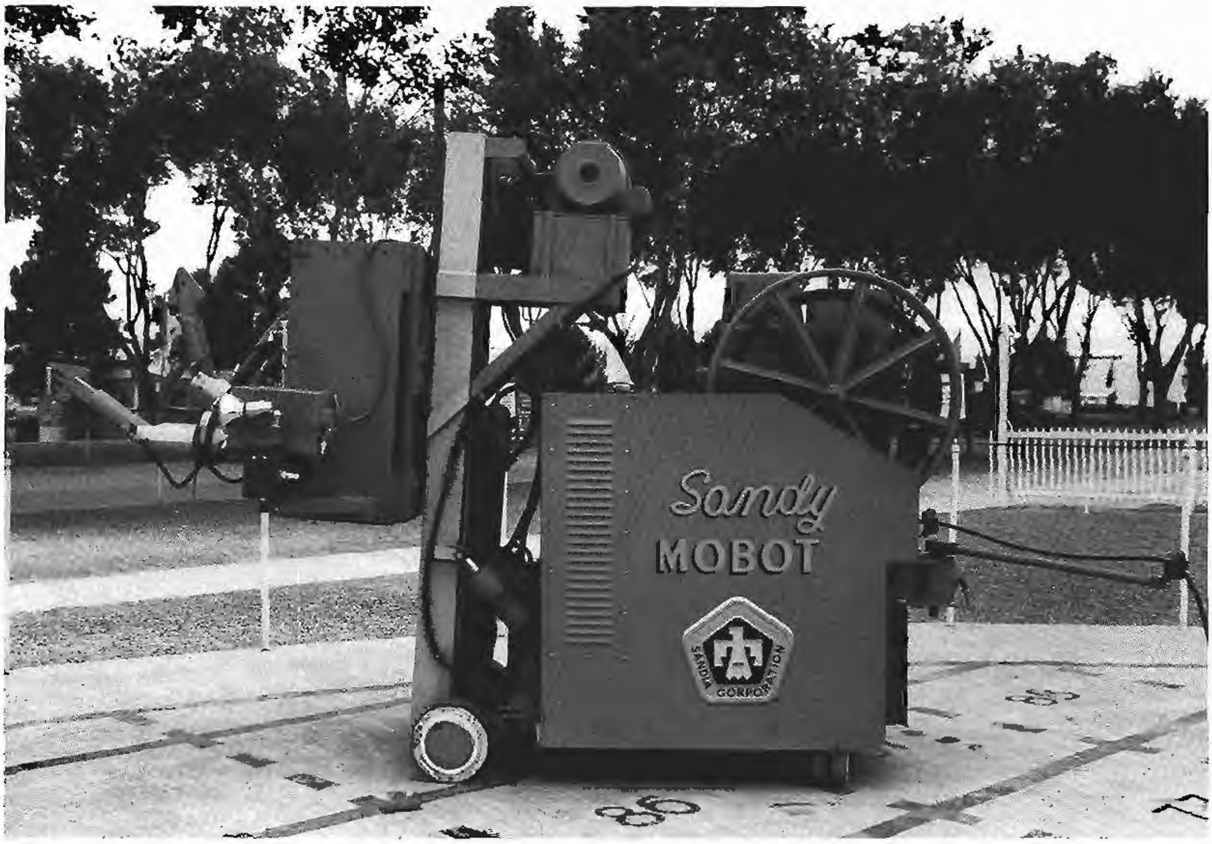
The radiation protection required by this new research equipment and reactors proved a challenge to Sandia's health physics section. The section was established in 1957 under the supervision of Harold Rarrick to perform radiation safety for Sandians participating in atmospheric testing. Rarrick, George Tucker, Bill Burnett, and Jim Metcalf managed the radiation safety for all Sandia and DoD nuclear tests from 1962 on.

A safety specialist prepares Glenn Fowler and James McRae for entry into a contaminated area after a nuclear test in the Pacific.

The nuclear testing moratorium came in response to worldwide concern about the fallout of radionuclides from clouds blown around the world after atmospheric tests. Fallout and an end to atmospheric testing became an issue in the 1956 presidential election, and in late 1958 the Soviet Union and the United States suspended nuclear testing. Although both nations reserved the right to resume testing, a temporary thaw in the Cold War ensued. A month after the testing moratorium began, Sandia finally installed a prominent corporate identification sign in front of its main public entrance at Building 800.

MCRAE'S LEGACY

James McRae left Sandia in September of 1958 to return east as vice president of AT&T and, until his death in 1960, as member of the AEC General Advisory Committee. Presiding over Sandia at the peak of weapon development and during the transition from fission to fusion designs when it participated in the development of nearly sixty weapon systems, McRae achieved an enviable management record.



Sandy Mobot (Sandia Mobile Robot), designed in 1958 to work in radioactive environments, became Sandia's first venture into robotics.

Arriving when morale problems still affected Sandia, McRae's appointment of Z-division veterans such as Glenn Fowler, Bob Henderson, and Dick Bice to corporate vice presidencies ameliorated early conflicts. This morale improvement came during a time when Sandia recruited more than 3,000 new employees, bringing the number of Sandians to 7,700 by the end of 1958. For these, McRae and his staff developed visionary educational and apprentice programs.

Under Quarles and McRae — with support from Mervin Kelly — Sandia applied enhanced engineering capabilities to the resolution of numerous design challenges. Among its notable achievements were thermal batteries, Zippers, environmental sensing devices, and other innovations in the quest to develop wooden, building-block, and laydown weapons.

Plagued initially by complaints about quality, Quarles, McRae, and Sandia established a reputation for design speed and quality. For example, the general in command of Army Ordnance called McRae to say, "I want to talk to you in Washington because it takes us longer to develop a rifle bullet than it does for you to develop and get into production a complete new [nuclear] weapon."

In 1956, Sandia opened a new laboratory in California, staffing it with a thousand highly resourceful personnel, and in the same year helped to open the Pinellas plant for neutron generator production. In 1957, it initiated an expanded research program and acquired its first accelerators and nuclear reactors to support this research. Thanks to the leadership of Glenn Fowler as vice president of research, Sandia during the mid-fifties launched its first ventures into computer modeling and solid-state electronics. In addition, it began exploration of plastics, microwaves, metallurgy, and materials sciences.

FREIGHT'S THEIR BUSINESS

These 1952 scenes reflect the daily hustle and bustle of the Shipping Department.

Shipping and Receiving

With an eye to safety, the men and women of the Shipping and Receiving Division kept freight moving and the wheels of Sandia's progress turning. During October 1952, Bob Copeland's Shipping and Receiving Division handled an average of 81 1/2 tons of inbound and outbound shipments every day. They were problem solvers and when a challenge came along that was a little bigger than usual, they just spit in their palms, hitched up their pants, and dug in. For example, when a 28-ton lathe ordered by one of the shops in the Laboratory arrived, the employees pitched in to get the equipment unloaded and delivered all in one day.

By 1952, 50,000 individual shipments passed through Shipping and Receiving each year. To handle and process quantities like these, a lot of manpower was required as well as a flexible, efficient recording system to track shipments. A typical day's operation at the warehouse saw huge trailer trucks backing up to loading docks, freight cars switching onto sidings, fork lifts carrying ponderous weight about the warehouse floor, and little hand cars scurrying from stack to stack. The pace did not slacken as the years passed — by 1995 materials shipped had increased to about 288,000 items. Although the workload grew, the department's commitment — to package and deliver materials cost effectively, efficiently, and safely — remained the same.

Accidents were a looming threat in Shipping and Receiving — the constant movement of men and heavy objects meant that one careless move could result in a serious injury. However, from 1947 through 1952, there was only one lost time accident. The Division's Safety Committee was responsible, to a large extent, for the excellent safety record. Personnel joined with the Safety Committee to discuss ways of solving safety problems. These exceptional safety practices allowed Shipping and Receiving to safely make "freight their business."

Siegmund "Monk" Schwartz was Sandia president from 1960 to 1966.

III

FROM MORATORIUM TO TEST BAN TREATY

Weapons and striking power will never settle anything, but a recognized superiority in this area will give our statesmen the maximum amount of time to achieve a lasting peace. The long term future is completely in their hands; we can only buy them time.

Robert Henderson

Responding to worldwide concerns about radionuclide fallout from atmospheric testing, the United States and the Soviet Union agreed in the summer of 1958 to suspend nuclear testing by November 1, reserving the right to resume when other nations did. Both accelerated their testing schedules during 1958 to obtain as much weapon data as possible before the moratorium. Then, in 1961, both began to consider a resumption of testing.

Once the testing moratorium began, the AEC recommended maintaining its three weapons laboratories as "vigorous and broad research and development institutions," but dismantled the testing task force in the Pacific and reduced Nevada Test Site (NTS) activities to a minimum. As the moratorium extended into the 1960s, Sandia's rapid expansion of the 1950s ceased; by 1961 it faced its first reduction-in-force.

Efforts by Sandia's senior management to keep its work force challenged and busy during the moratorium bore fruit far exceeding expectations, beginning with participation in a significant non-weapons project — the VELA program for nuclear burst detection. Its research expanded into new fields, its exploratory programs produced revolutionary weapons designs, and some of its technology began to spin off from weapon development into the private sector.

When the Soviet Union resumed nuclear testing in 1961, the United States found itself unprepared to start testing again immediately. In response, Congress demanded safeguards to maintain the readiness of the U.S. nuclear weapon research and development program in all of its facets.

ANTICIPATING THE MORATORIUM

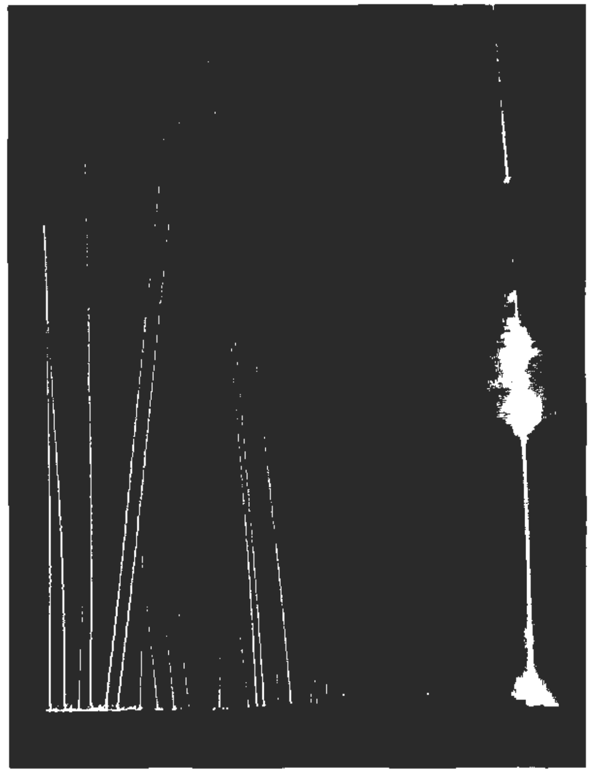
Before the test moratorium began in November 1958, the United States rushed to complete weapon development, weapon effects, and safety tests conducted in the atmosphere, at high altitudes, and underground. These included the Hardtack I atmospheric and high-altitude test series in the Pacific from May into August of 1958, the Argus tests in the South Atlantic in August and September of 1958, and the Hardtack II tests at NTS in September and October of 1958. Out of these tests came several new Sandia capabilities.

Don Shuster, a native New Mexican, became commander of the scientific task group for the 1958 Hardtack I task force, including 150 Sandians, that conducted the thirty-five nuclear tests in the Pacific. The scientific deputy to the task force commander was William Ogle of Los Alamos. After Hardtack, Shuster managed Sandia's full scale test unit until 1961 when he became director of field test. In 1962, he served as associate scientific deputy for the Dominic Fishbowl high-altitude test series. He later directed aerospace programs, exploratory development, advanced systems development, and energy initiatives. Considered a genius by his contemporaries, it became a truism that wise managers at Sandia should "hire people like Shuster and leave them alone."

For the high-altitude Hardtack I tests, Shuster and Glenn Fowler initiated an expanded rocket testing program to supplement the aircraft carrying diagnostic instruments that flew near the mushroom clouds. Sandia had designed its first rockets in 1957 to test warhead fuzes and formed a rocket aerodynamics group led by Harold Vaughn. To collect data on weapon radiation, blast, radio frequency, and electromagnetic effects during Hardtack's high-altitude tests, Sandia designed more rockets to carry instrumented telemetry aloft from Johnston Island. Launched at the same time as missiles carrying the warheads, rocket-borne instruments provided data on device performance and output and on the interaction of these with the natural environment.

After launching 130 rockets in connection with Hardtack I, Sandia continued experimenting with diagnostic rockets, in time becoming a leader in small, unguided rocket design and testing under the leadership of Morgan Kramm, John Eckhart, and Dick Eno. It used rockets for exploratory weapon development in testing the designs of parachutes, reentry vehicles, and earth penetrators. Including experiments it performed for Los Alamos, Lawrence Livermore, the Air Force, NASA, and other agencies, Sandia eventually conducted approximately 1,500 rocket launches at sites around the world, although most were done at its own launch facilities at the Tonopah, Nevada and Kauai, Hawaii test ranges.

When Sandia supported the Navy for the Argus tests scheduled for September 1958, John Ford, Bill Myre, James Leonard, and Don Cotter headed the Sandia teams designing and testing arming, fuzing, and



Launch of Starfish Prime during Hardtack I in the Pacific. This photograph shows the Thor's track to the right and the instrumentation rocket paths to the left.

firing systems to be mated with warheads on the Lockheed-built missiles. The schedule allowed six weeks to design equipment, fabricate test units, adapt devices to the missiles, create the telemetry, assemble and ship the test units, and perform preflight checks ashore and at sea. According to Ford, after "great strain and many frustrations" Sandia met its schedule.

Oscar Fligner and other Sandians accompanied a Navy task force to the South Atlantic for the Argus tests. These tests explored a theory that charged particles emitted by fission fragments generated by a high-altitude detonation would be trapped by the earth's magnetic field and form artificial aurorae. The concern was that this shell might be intense enough to cause severe damage or even destroy a missile passing through it. In the first and last ship-launched rocket-borne nuclear tests by the United States, Argus indicated that nuclear bursts did release electrons into the earth's magnetic field, but not enough to damage incoming missiles. They also caused radar

During the 1950s, Sandia developed balloons capable of carrying test instrumentation and even nuclear devices aloft. Here, H. Gerald Laursen stands beneath an instrumentation balloon.

blind spots, an important consideration for missile defense.

During the Hardtack II series in Nevada, Sandia suspended nuclear devices from tethered balloons designed initially for the 1957 Plumbbob tests as a substitute for more expensive towers. Reducing test costs and radioactive fallout, balloons became a new Sandia specialty. During Hardtack II's underground tests, Sandia also initiated a geological research group that included Bill Perret, Jim Shreve, and Byron Murphey, which investigated ground motion and seismic shock. This research later became an important aspect of treaty verification evaluations and proved useful for subsurface studies of proposed nuclear-waste storage sites.

THE MORATORIUM BEGINS

As the Hardtack II test series ended and the moratorium began, Mervin Kelly retired and James McRae returned east to become coordinator of defense activities for the Bell system as a vice president of AT&T. "The future of our civilization depends on advancing science and technology," McRae predicted before leaving, admonishing that "we must no longer regard our scientists and engineers as merely unimportant squares or eggheads."

Julius Molnar of Bell Laboratories succeeded McRae at Sandia. After earning his doctorate from the Massachusetts Institute of Technology, Molnar worked for the National Defense Research Committee during World War II and joined Bell Laboratories in 1945 for electronics and microwave research, becoming vice president for military programs.

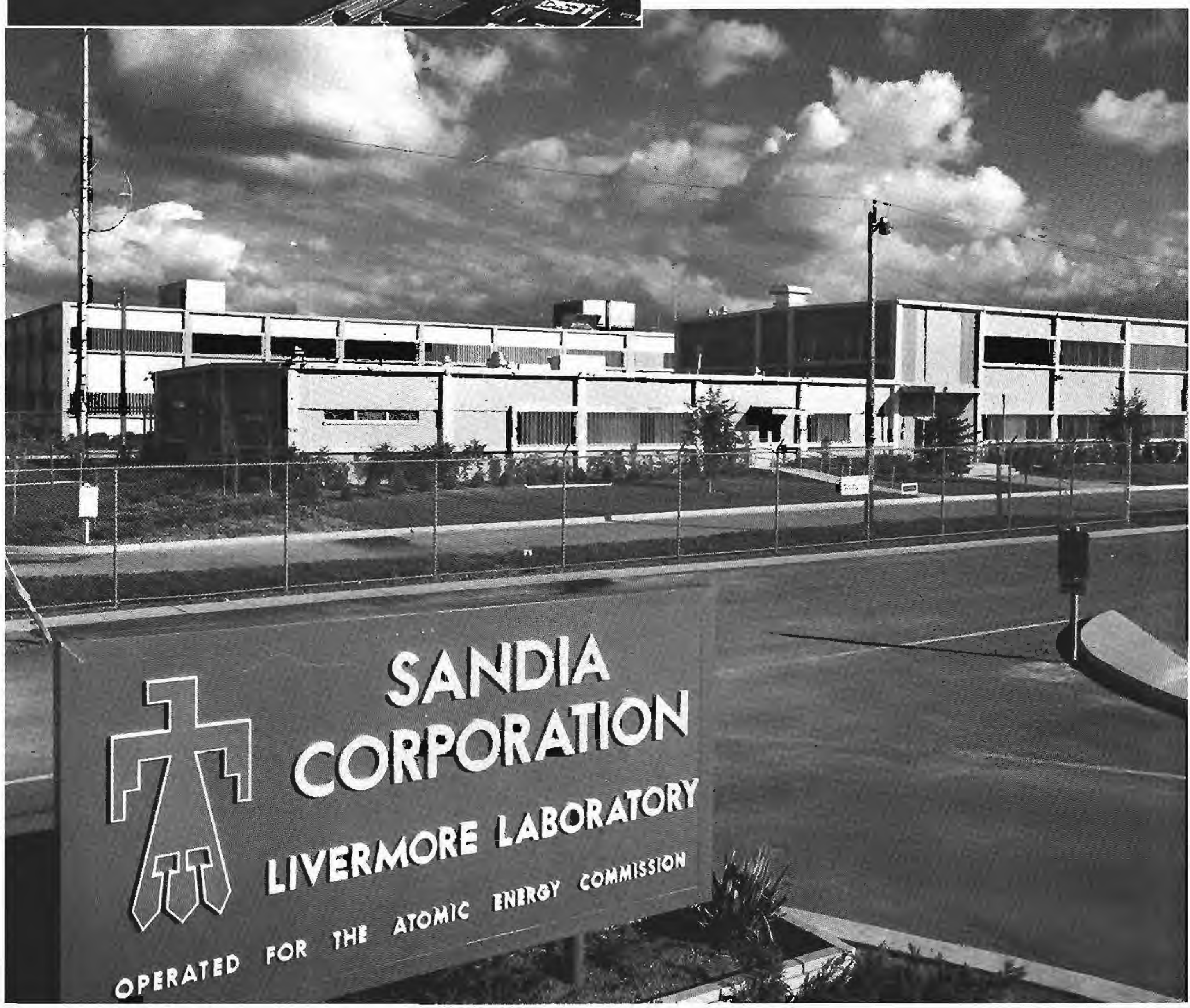
Molnar kept Monk Schwartz as his general manager and employed more administrative staff. In December 1958, he also approved changes in Sandia's name. Sandia Corporation remained the legal name for the organization, but since "laboratory" seemed more descriptive of an increasingly research and development oriented organization, the New Mexico and California sites were referred to as Sandia Laboratory and Livermore Laboratory, respectively.

At the moratorium's onset, General Alfred Dodd Starbird, AEC Director of Military Applications, planned reductions in the weapon development budget and sought to

Sandia president Julius Molnar and general manager Siegmund "Monk" Schwartz. Schwartz succeeded Molnar as president in 1960.

A 1961 aerial view of Sandia's California site. Across the street is part of Lawrence Livermore Laboratory visible in the lower left corner.

The entrance to Sandia's California facility in 1958.

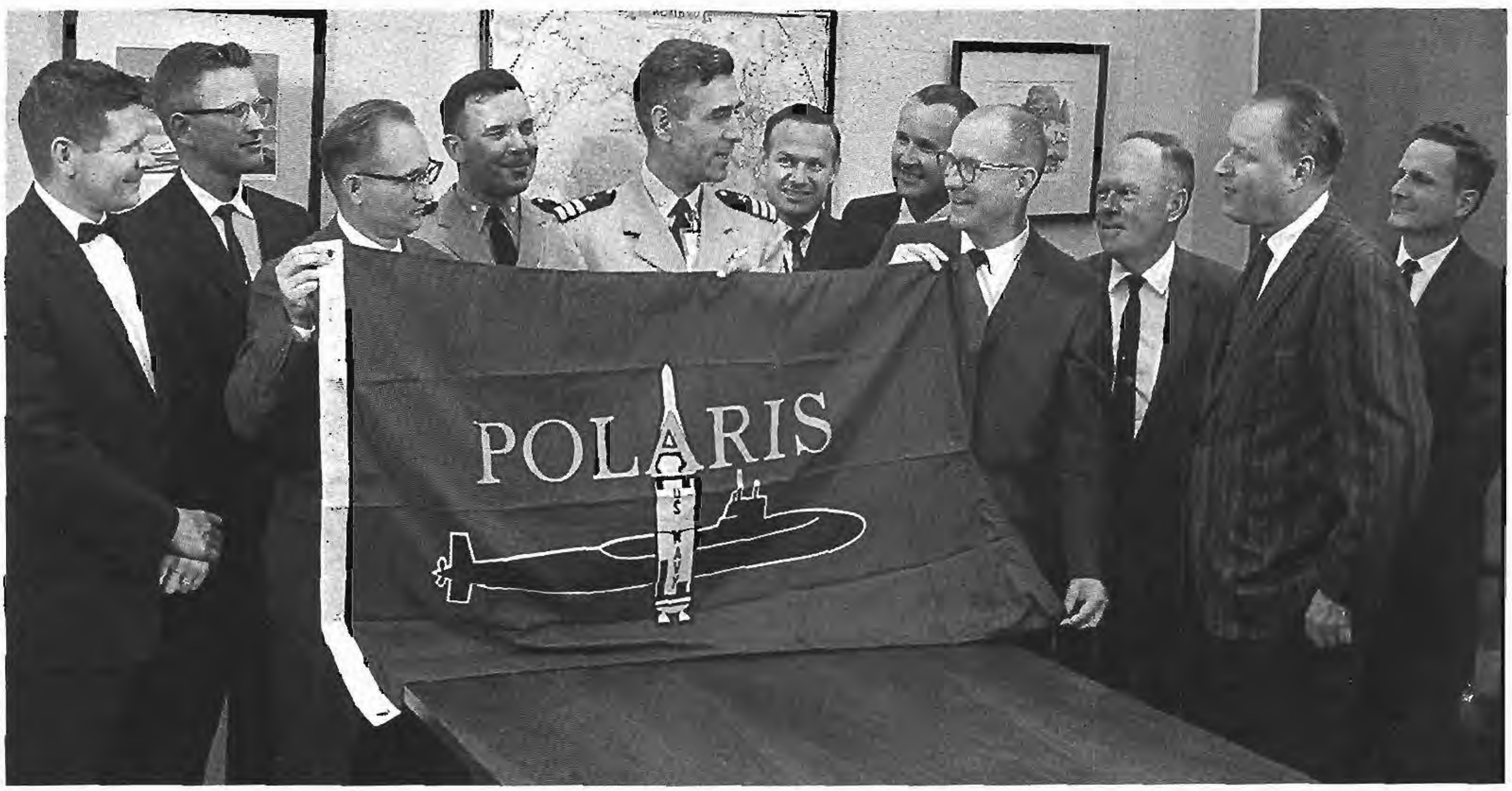


impose personnel ceilings on Sandia and its partner laboratories. Sandia resisted staff ceilings, insisting it should manage its own personnel in accordance with the "good industrial practice" mandated in its contract while carefully staying within the budget allocated by the AEC. Starbird's proposed ceiling of 7,900 personnel prevailed, however, and Sandia's decade-long growth ceased. In 1959 and 1960, the number of Sandians leveled off at 7,860; and in 1961, for the first time in its history, Sandia laid off personnel, reducing the number to 7,800. It was, however, spared the precipitous declines experienced elsewhere during the moratorium.

Before the moratorium began, the Sandia and Los Alamos design team developed a warhead for the Atlas, Jupiter, and Thor ballistic missiles. Using several major subsystems from the W28, they put the W49 warhead, complete with the first environmental sensing device, into the stockpile in 1959.

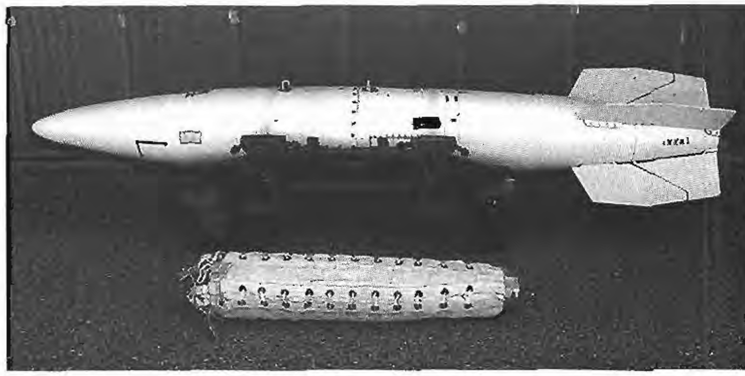
Ten weapons projects moved through design into production during the three-year moratorium. John McKiernan led Sandia's engineering design team for the W50 warhead for Nike-Zeus and Pershing I. Alfred V. "Vic" Engel and Sam Moore headed teams that in 1962 completed the W52 warhead design for the Sergeant missile. After problems with an electromechanical timer were solved, the small B54 Special Atomic Demolition Munition became the subject of several exploratory studies. Bob Grover, Jim Cocke, and Jim Jacobs, for example, studied use of the munition in atomic projectiles for Army artillery and Navy guns.

For the Navy, Sandia participated with Lawrence Livermore in design of the W55 warhead for the SUBROC antisubmarine missile and the W58 warhead for the Polaris A3 missile. For the Air Force, Sandia participated in designs of the W38 for Titan I, the W59 and W56 for the Minuteman family of intercontinental ballistic missiles, plus two bombs, the B53 and B57.



Navy Commander Alexander Julian presented the Polaris flag to Sandians who worked on this project. *Left to right:* Lee Davies, Ed Daugs, Gene Aas, William Boyer (Navy liaison), Julian, Bob Dougherty, Joe Sladky, Hilton DeSelm, John Larned (AEC), Ray Brin, Vern Field.

A 1958 Operation Hardtack test pointed the way to the B53 high-yield thermonuclear bomb, which the Strategic Air Command would carry on its B-47 and B-52 bombers as well as the proposed B-70 aircraft. Charles Carpenter and Ed Bruce successively managed the Sandia project teams that designed this full-fuzing option bomb with a laydown capability. It entered production in 1962. In 1960, Sandia began adapting the warhead part of the B53 for service aboard Titan II missiles.



Sandia began development of the B57 tactical bomb during the moratorium.

A B53 JTA (Joint Test Assembly) is shown on the hard target at Tonopah Test Range.

Bill Denison and a group including Stan Spray, Herb Filusch, and Emil Kadlec completed the B57 bomb project that began in 1959. This lightweight, multipurpose bomb met Air Force needs for a tactical, full-fuzing option weapon and the Navy's needs for a small nuclear depth charge. Modifications to the B57 bomb design continued at Sandia until the late 1960s, and the weapon remained in the stockpile until 1992.

In late 1961 and throughout 1962, three weapon programs faced delays if large quantities of reliable electromechanical selectable-interval timers were not available. Serious production difficulties at the manufacturer's plant led Bob Henderson to form a special task force operation that was given the highest priority within Sandia. Overall director of the task force was Lou Hopkins, with Doug Ballard heading a seventeen-member Sandia design and manufacturing development group assigned to the supplier's plant and Carmen Gabriel handling the supporting operations within Sandia.

During the ten-month tenure of the task force, extensive design and manufacturing improvements solved the reliability problems and more than five thousand timers were ultimately produced to meet the urgent needs of the weapon systems. Despite the moratorium, enhancing the safety of deployed nuclear weapon systems continued to be a major issue. This process reached a major watershed in June 1960 with the issuance of a DoD directive that had been developed jointly with the AEC. This document defined four qualitative standards designed to "assure that atomic weapon systems incorporate the maximum safety consistent with operational requirements."

Parachute test drop of a JTA.

Sandia launched these two-stage rockets to measure blast, radiation, and electromagnetic effects during 1958's high-altitude tests in the Pacific for Operation Hardtack.

The four standards were:

1. There shall be positive measures to prevent weapons involved in accidents or incidents or jettisoned weapons from producing a nuclear yield.

2. There shall be positive measures to prevent deliberate arming, launching, firing or releasing of nuclear weapons except upon execution of emergency war orders or when directed by competent authority.

3. There shall be positive measures to prevent inadvertent arming, launching, firing or releasing of nuclear weapons in all normal and credible abnormal environments.

4. There shall be positive measures to ensure adequate security of nuclear weapons.

Remarkably, these standards survived almost unchanged for nearly thirty-five years and continue to form the foundation of nuclear weapon system safety. In addition, they became strong forcing functions in Sandia's warhead electrical system designs.

The four standards became the charter for the Nuclear Weapon System Safety Group, originally formed by the Air Force in 1958 and followed shortly thereafter by the Army and Navy. These organizations, which included members from the military services, the Armed Forces Special Weapons Project, and the AEC, with Sandia as a technical consultant, were charged with performing an independent evaluation of the nuclear safety of all nuclear weapon system operations.

In order to focus the Laboratory more clearly on technical work, Starbird relieved it of the responsibilities for maintaining the AEC housing at Kirtland along with the motor pool, office equipment service, and security support it provided the AEC's Albuquerque office. In 1960, the AEC transferred its housing adjacent to Sandia to the military services, ending the separation of Sandians in a "company town" outside the greater Albuquerque community.

Additional staff flexibility came from Sandia's exit from the nation's weapon storage sites as a result of the introduction of sealed-pit weapons. For continuing evaluation of the stockpile, Sandia designed quality evaluation stockpile testers (QESTs) capable of assessing the performance of the entire arming and fuzing system of a weapon in one laboratory located at the Pantex assembly complex in Amarillo, Texas. With the cooperation of the Defense Atomic Support Agency, created in 1959 to replace the Armed Forces Special Weapons Project, Sandia withdrew its personnel from the storage sites by 1960.

AEC security requirements loosened slightly during the moratorium. As a result, Molnar approved plans by public relations manager Ted Sherwin for a Family Day in 1959. That April, Sandia opened unclassified areas to its employees' families, and many children learned for the first time something of their parent's work.

Visitors view Sandia's machine shop in building 840 at the first Family Day in 1959

Among other marks of the moratorium's reduced tension were a corporate identification sign erected outside Sandia's main entrance on Wyoming Boulevard, recruiting advertisements Sandia placed in such magazines as *The New Yorker* and *Newsweek*, and increased emphasis on publication and participation by Sandians in professional conferences. Managed by Richard Claassen, Craig Hudson, and George Anderson, the Sandia colloquium program, established in 1954 to promote scientific exchange, broadened its invitations to include such policy makers as George Kistiakowsky, Edward Teller, Arthur Compton, Hans Bethe, and Henry Kissinger.

DIVERSIFICATION INITIATIVES

In the face of changing national priorities, New Mexico Senator Clinton Anderson of the Joint Committee on Atomic Energy asserted that Sandia represented a valuable federal investment in facilities and human talents. He suggested that, if demand for weapons waned, Sandia should be shifted to other research, perhaps in the AEC's nuclear energy and space programs. Julius Molnar speculated that Sandia might in time become one of the Bell Laboratories, perhaps specializing in defense communications in addition to weapons. "It is my strong conviction," he concluded, "that the only wise and prudent thing to do is to maintain Sandia's capabilities by having it work in other areas."

Molnar discussed diversification of Sandia's programs with General Starbird, declaring it "imperative for Sandia to branch out into new fields of endeavor." He hoped that by 1962 Sandia could have as much as a quarter of its efforts devoted to non-weapon projects. Starbird replied that during the moratorium Sandia should concentrate on three tasks: maintaining adequate staff for component and systems development, performing applied research for weapons, and undertaking other activities as needed to keep experienced staff from departing.

Sandia's first opportunities to diversify came via requests from its partner laboratories for engineering support of their peacetime projects. At the request of Norris Bradbury of Los Alamos, Robert Henderson sent Sandians to NTS, where they coordinated engineering for the Rover project, the design of a nuclear reactor to power space rockets for NASA. Other Sandians provided engineering support for Los Alamos in James Tuck's Sherwood project, involving experimental machines for magnetic confinement of a hydrogen plasma, with the long-term goal of generating energy through fusion. Sandia also joined in Bradbury's venture into an experimental Turret nuclear reactor for power production. Indeed, Bradbury wanted Sandia to build the pilot reactor, but Starbird vetoed that on the grounds that other AEC laboratories should handle reactor design for power production.

In June 1961, Molnar's successor, Monk Schwartz, set up a small directorate led by Don Cotter to think about work for others.

Don Cotter became director of advanced systems research in 1961.

University of New Mexico president Tom Popejoy, *center*, meets in 1959 with Glenn Fowler and Julius Molnar of Sandia.

As will be discussed in the next chapter, this group examined a variety of areas of potential work for Sandia, including solar and wind energy, medical electronics, nuclear power safety, and many others.

PLOWSHARE

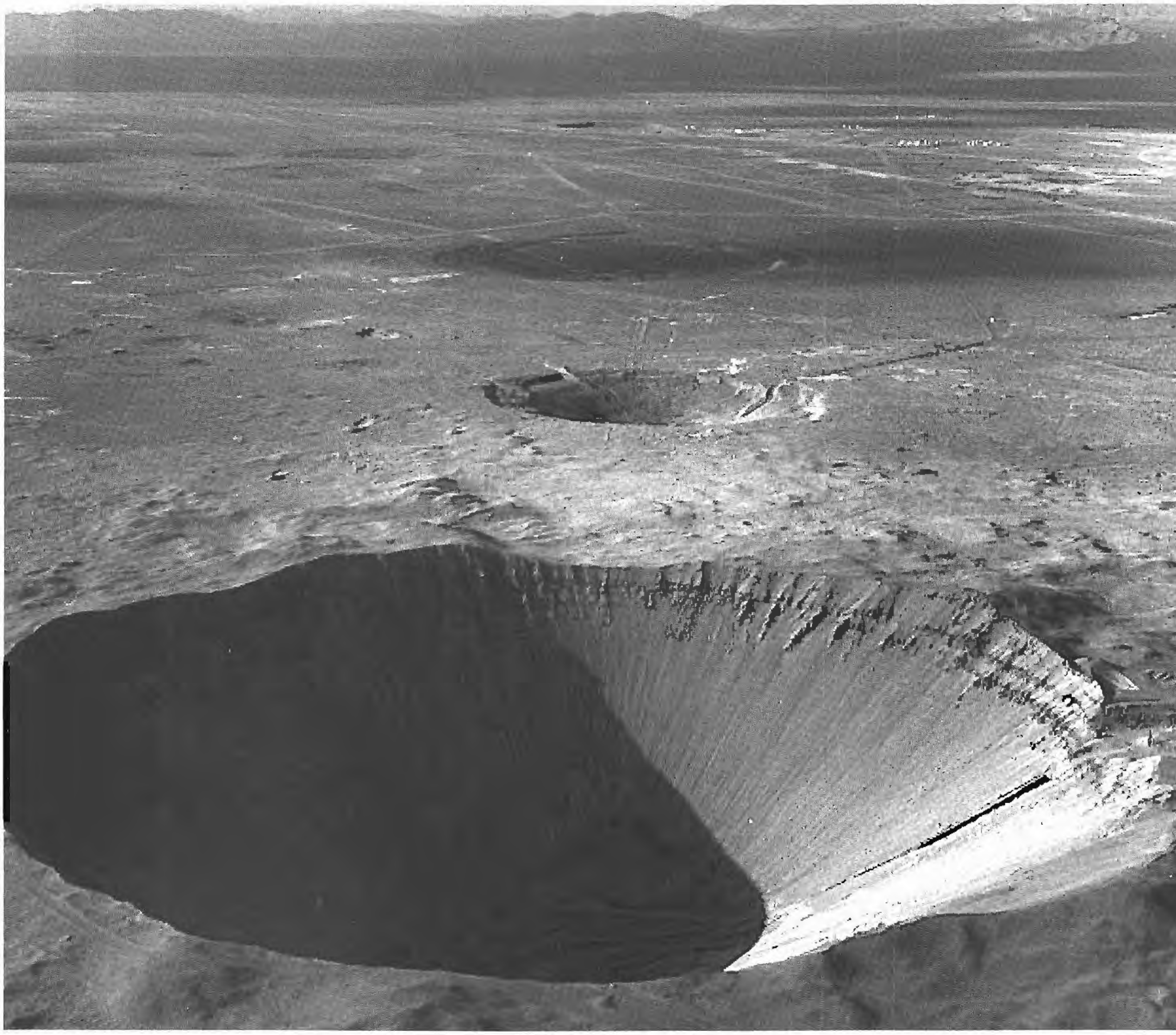
Another significant area of Sandia diversification came with Project Plowshare. The concept of Plowshare, from the scriptural exhortation to beat swords into plowshares, has been credited to Edward Teller. Plowshare began in 1957 under the technical direction of Lawrence Livermore Laboratory to consider using nuclear explosives for peacetime excavation projects and for recovering oil from deposits that drilling and pumping systems alone could not tap. They might be used as well to generate underground steam to drive electric power turbines, or to produce radioisotopes needed for medical diagnosis and other purposes.

Sandia's background in ordnance engineering and field testing yielded Plowshare assignments. In 1959, Glenn Fowler met with the AEC and the Governor of the Panama Canal Zone to discuss "a second Panama ditch," the use of nuclear explosives to quickly open a sea-level canal across the isthmus. Richard Bice accompanied Teller to Alaska to study nuclear excavation of a harbor. After discussions with Teller, Molnar agreed that Sandia would conduct explosives field experiments and provide fuzing and firing engineering for the nuclear devices. Canal and harbor engineering would be done by the Army engineers and oil and mineral recovery designs by the Bureau of Mines.

As Plowshare proceeded, Sandia investigated the necessary yields of the nuclear devices, how deeply they should be buried, how to arm and fire them, and how to assure blast safety. Luke Vortman led the team devoted to cratering engineering, using high explosives to learn how best to place nuclear explosives to perform excavation. Among these was the 1960 Scooter test in Nevada, using a million pounds of TNT in the largest conventional high-explosive detonation in theUnited States. Through these cratering experiments in Nevada and New Mexico, Vortman and his associates learned that the smoothest trenches could be excavated by simultaneous detonation of explosives with a uniform spacing about equal to the optimum depth at which the charges were buried.

Recruiting advertisement by Sandia Corporation that appeared in *The New Yorker* and *Newsweek* in 1958.


Luke Vortman led Sandia's Plowshare cratering experiments.



Aerial view of Sedan crater at Nevada Test Site. This underground nuclear test in the Plowshare series was sponsored by Lawrence Livermore Laboratory.

In 1964, Congress authorized a feasibility study of a new sea-level canal across the Panamanian isthmus. President Johnson appointed an Atlantic-Pacific Interoceanic Canal Study Commission to oversee a number of working groups from the Corps of Engineers and the AEC focusing on different aspects of using nuclear devices. Vortman's analysis indicated a sea-level canal across Panama could be opened with nuclear explosives in half the construction time and at a quarter the cost of conventional explosives. In addition to investigating canal possibilities, the cratering studies explored the possibility of building harbors and overburden removal in mining using nuclear explosives.

As the canal studies proceeded, an experimental program was added to investigate the results of using adjacent simultaneous underground explosions for cratering. Bill Perret led Sandia's participation in this aspect of the research, working with the New Mexico Institute of Mining and Technology.

While Vortman and Perret studied cratering, Sandia meteorologist Jack Reed led a group conducting air blast studies. Concerned with blast safety prediction, the group designed experiments to examine and determine the potential long-range air blast damage from a nuclear explosion. Propagation mechanisms were studied in a long series of upper air meteorology observations conducted at Battery McKenzie near the Atlantic entrance to the Panama Canal.

The Plowshare program involved several tests of nuclear explosives. Dean Thornbrough and Wendell Weart led the Sandia team at the 1961 Gnome shot in an underground salt dome near Carlsbad, New Mexico. This multipurpose experiment examined the use of heat left in the explosion's cavity to power turboelectric generators, the recovery of radioisotopes from the cavity for medical and industrial applications, determination of neutron cross sections for heavy metals, and the effects of nuclear blasts on salt formations.

In 1962, the second Plowshare test, named Sedan, explored the feasibility of nuclear excavation with an underground device that moved about twelve million tons of earth, leaving an impressive crater at NTS. Similar excavation experiments with both high explosives and nuclear devices continued throughout the 1960s with Vortman and Reed as advisors. Project Buggy, for example, involved the simultaneous detonation of a row of five nuclear devices at NTS that produced a 900-foot long by 80-foot deep trench resembling a canal section.

Project Buggy should not be confused with Project Gasbuggy, a 1967 test east of Farmington, New Mexico. A government-industry partnership including the AEC, the Bureau of Mines, and the El Paso Natural Gas Company sponsored the Gasbuggy study of how nuclear explosives might be used to stimulate the recovery of natural gas from sandstone formations. Similar tests of recovery from gas-bearing sandstone, Projects Rulison and Rio Blanco, occurred in 1969 near Grand Junction, Colorado. Perret directed Sandia's ground motion studies on all of these tests.

Although early Plowshare test results appeared promising, public concerns about the environmental effects both of nuclear excavation and of the potential transfer of flora and fauna through a sea level canal increased, and funding for the program slowly declined. Sandia's role in this peaceful research remained small, as did its role in non-weapons research for Los Alamos. Together, these projects involved fewer than one hundred Sandians, and Molnar was not satisfied. "We need forward-looking peacetime activities if we are to maintain a vigorous staff," he said. "Such activities will also enable us to care for peak loads in weapons programs."

TONOPAH TEST RANGE

The 1958 testing moratorium did not extend to the testing of non-nuclear ordnance, and Sandia continued its engineering design tests by opening a permanent test range in 1960 near Tonopah, Nevada. Because encroaching commercial air traffic and limited land-target area constrained use of the Salton Sea range, Sandia tested bomb contact fuzes during the mid-1950s at Yucca Flats in the Nevada Test Site. Full-scale nuclear testing there, however, had interfered with Sandia's tests. Needing a concrete target to test laydown bombs, it used an abandoned aircraft runway near Dalhart, Texas, for the purpose. At the same time, Sandia joined the Air Force and Navy in efforts to find a site for a joint ballistics testing range and identified a promising location near Winslow, Arizona, but this site included part of the Navajo reservation and would have required relocation of some of the population.

While working at Yucca Flats, Howard Austin, Bobby G. "B. G." Edwards, Ben Benjamin, and Don Beatson found a promising test range site in the northwestern corner of the Las Vegas bombing range. Known as Cactus Flats, this high, barren desert valley afforded easy approaches for low-level aircraft test drops and also had several dry lakebeds that could serve

Joshua trees of the high desert frame Sandia's radar and tracking stations at Tonopah Test Range, Nevada.

admirably as targets. It had been used as a bombing range during World War II by aircraft from a base thirty miles north near the mining town of Tonopah, Nevada. No relocation of people was needed because the Air Force had acquired the valley earlier, and the site was remote from commercial airlines and even from radio signals that might interfere with telemetry. Wild horses and antelope did live in the area, but none were ever injured during Sandia's testing.

With permission from the Air Force, Sandia installed temporary buildings and instrumentation at the Tonopah site in 1957 and began using it for inert bomb tests. During the late 1950s, field test units stationed at Salton Sea commuted to Tonopah regularly for testing over land targets. At Glenn Fowler's recommendation, Sandia made Tonopah a permanent test range, finally closing its Salton Sea base in 1961. With the construction of a concrete target and operations buildings and the installation of radar, tracking cameras, and other instrumentation, Tonopah became four test ranges rolled into one. It provided a high-level bombing range over dry lakes, a low-level bombing range with its concrete and land targets, a rocket launching range, and facilities for test firing artillery shells. The uniform texture of sediments in its dry lakebeds proved excellent media for cratering experiments in connection with Plowshare and for testing earth-penetrating weapons as well. As Sandia's permanent test range, Tonopah served its purposes well throughout the remainder of the Cold War.

Tonopah Test Range control point in 1960.

Los Lunas, Salton Sea, Yucca Flats, Tonopah, and Kauai

Sandia provided technical support for ongoing nuclear testing in the Pacific and at the Nevada Test Site from 1946 to 1992, as well as participating in specialized nuclear tests at other sites. The Labs also conducted extensive testing of non-nuclear weapon components in a variety of different environments both at home and around the world, creating temporary test sites or using the existing test facilities of other agencies. For example, in the cold early months of 1951, Sandia dropped non-nuclear Mark IV's into Upper Red Lake, Minnesota to evaluate baroswitch performance in low temperatures. Sandia also used a site in Edgewood, New Mexico for about a decade beginning in 1968 to conduct Davis gun and terradynamic studies. However, most of Sandia's testing was done at the test range facilities it operated in Los Lunas, Salton Sea, Yucca Flat, Tonopah, and Kauai.

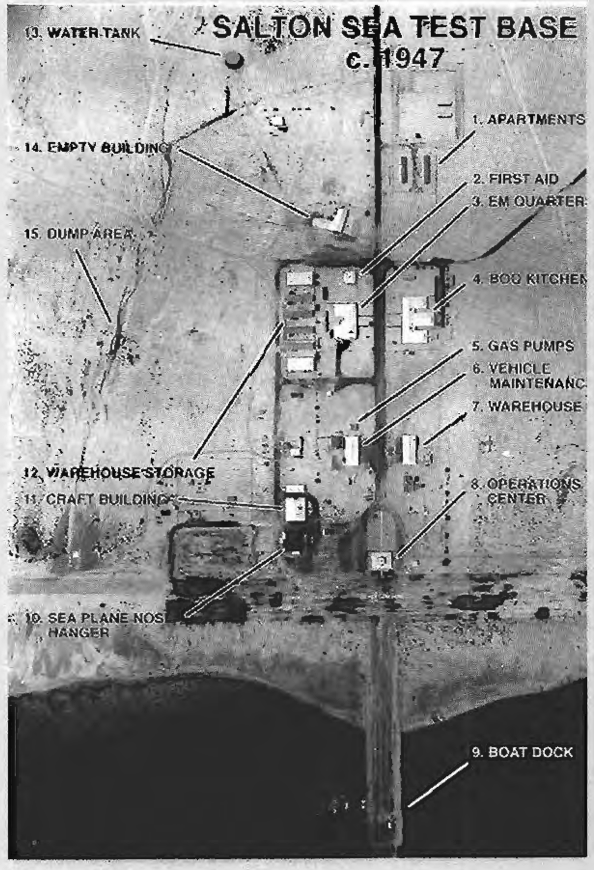
In late 1945, Sandia began testing its bomb designs at the Los Lunas Range a few miles southwest of Albuquerque. Other than target and camera-station markers, Sandia built no facilities at this range, instead trucking instruments to the range for each test. Testing at Los Lunas focused on bomb ballistics and mating bombs with aircraft delivery systems. Sandia used the Los Lunas range intermittently until 1959.

Because Los Lunas was at a high elevation, Sandia sought a range that would permit testing bombs nearer to sea level. In 1946 it acquired a Navy test range in California at the Salton Sea — 200 feet below sea level. At the Salton Sea Test Base, Sandia built permanent instrumentation stations and an operations center, and provided temporary housing for more than 100 employees. Used chiefly to test strategic bombs dropped from high altitudes, this base closed in 1961, replaced by the Tonopah Test Range.

As commercial air traffic and atmospheric haze from California cities interfered with testing at Salton Sea, Sandia sought another range. Yucca Flats at the Nevada Test Site provided a level land target to test bomb impact fuzing from 1954 until 1958. Building no permanent facilities at Yucca Flats, Sandia used temporary buildings and trailers for mobile test instrumentation. At this time also, Sandia tested laydown bomb designs on abandoned airfield runways near Dalhart, Texas, and Chincoteague, Virginia.

While searching for a permanent range, Sandia found a site at Cactus Flats on the Las Vegas bombing range (Nellis Air Force Base) and leased it as a temporary test site in 1956. Until 1960, Sandia's field test crew commuted between Salton Sea and this site, named Tonopah Test Range after nearby Tonopah, Nevada. Sandia made Tonopah its permanent test range in 1960 and closed Salton Sea. The range operating crew first lived at Tonopah, but moved in 1968 to Las Vegas, commuting to the range and back by aircraft. In the following decades, the Tonopah range became multipurpose: supporting aircraft drops, rocket launches, artillery firing, parachute development, and a variety of other tests.

During the last U.S. atmospheric nuclear tests in 1962, Sandia established a rocket-launching facility on Kauai in the Hawaiian Islands. First known as Barking Sands, it became the Kauai Testing Facility. Located on the Navy's Pacific Missile Range, Kauai was where Sandia tested designs for high-altitude rockets. Both rail-launch and vertical-launch facilities at Kauai supported the testing of hundreds of rockets over the years, and Sandia upgraded the Kauai facilities during the 1980s to test Strategic Defense Initiative equipment.



Salton Sea Test Base in 1947.

Kauai Test Facility in 1991.

Bob Graham and Frank Neilson inspect a quartz gauge for shock stresses developed in 1962 on the basis of their research on piezoelectric crystals.

Ed Litzaw at Sandia California in 1961 demonstrated Sandia's first fiber-optics probe for viewing internal components without disassembly. He noted these probes might be used to examine the interior of combustion engines and even the human body.

A lab-built laser produces a thin beam of coherent light. Charles Bates used this laser to check a theory about infrared transmission.

RESEARCH INITIATIVES

With the addition of these new test facilities, Sandia increased its capabilities for both basic and applied weapons research. The Laboratory recruited nationwide to add a second generation of engineers and scientists to contribute to the science and technology base undergirding engineering at Sandia. From Bell Laboratories came managers to direct Sandia's research; and Sandia opened laboratory facilities during the moratorium for materials, standards, ceramics, metallurgy, electronics, integrated circuits, radiation effects, and solid state physics. "Our responsibility as scientists," observed Frank Hudson, "is to study the broad scientific territory which provides a foundation for Sandia's engineering activities."

Under Robert Townsend and Burnard Biggs during the 1950s, Sandia's materials laboratory engineered existing materials to meet the severe requirements of weapon design. Completing a materials laboratory building in 1960, Sandia brought additional specialists into materials research, specifically to design new materials at the molecular level. Among these were Nick DeLollis, a national adhesives expert called "Sticky Nick" by his friends, and Glen Kepler, who specialized in the use of organic polymers in ferroelectric and semiconductor devices.

The research initiative had early results. Among these was a controlled process for producing crystals for use as contact fuzes. In addition, Frank Neilson, Bill Benedick, and Bob Graham developed a high-resolution quartz gauge for shock-stress measurements that proved especially useful for studies of ferroelectric ceramics and shock-activated materials, and for measuring nuclear explosion-induced stresses in materials tested underground at NTS.

During the moratorium Sandia first explored the uses of lasers and fiber optics. George Dacey, involved at Bell Laboratories in the development of masers, lasers, and photonic technologies, became Sandia's research vice president at the time of the moratorium, and by 1962 Sandians were using focused light from ruby lasers to detonate explosives. At the same time, Ed Litzaw at Sandia's California site began using fiber-optic probes to examine the insides of weapons without disassembling them. Sandia also established an opto-electronics laboratory to investigate potential applications of photonics — the optical equivalent of electronics — to weapons.

Berta Guest conducted high potential tests on multiple contact connections in 1964 in Sandia's performance laboratory.

Gene Haertling inspects a furnace in Sandia's ceramics laboratory.

A new research field needing exploration became apparent in 1959 when Tom Cook chaired an Air Force Science Advisory Board study group that expressed concerns about the vulnerability of weapons to x-rays and

Elmo Hirni at work on the Van de Graaff accelerator, one of the early particle accelerators used at Sandia to study radiation effects.

gamma rays. "When you put any electronics in space," Cook declared, "you are going to have to pay a lot of attention to keep them from being disrupted at very long distances from nuclear weapons, or for that matter even from natural radiation environments in space." This concern was echoed by Bell Laboratories, then considering the use of transistors in space-based communication systems, which sent several senior scientists to Sandia in the early 1960s to study radiation vulnerability problems.

Katheryn Lawson investigated the infrared spectra of inorganic compounds in 1962.

Since full-scale nuclear testing to study x-ray effects could not be conducted during the moratorium, the AEC's weapon laboratories found other means of simulating weapon effects. Sandia acquired particle accelerators and completed its Engineering Research Reactor and its Pulsed Reactor in 1961. These permitted study of radiation damage to materials resulting from neutrons, electrons, gamma rays, and x-rays. Planning began as well for the Hermes accelerator that produced x-rays by bombarding metal targets with an electron beam. When completed in

1965, Hermes became the world's largest flash x-ray machine in terms of output, providing Sandia its first role in pulsed-power sciences.

The Sandia Engineering Reactor Facility began operation in 1962, but construction delays prevented it from becoming Sandia's first operational reactor. The Sandia Pulsed Reactor, a fast-burst reactor similar to the "unclad" Godiva reactor at Los Alamos, began producing neutron and gamma-ray pulses in 1961 for studies of radiation effects on materials ranging from transistors to entire missiles. D. Maxwell Ellett provided conceptual design and Vernon Kerr served as project engineer for the pulsed reactor, which, except for its nuclear core, was built in Sandia's development shops and installed in a domed igloo near the engineering research reactor.

The Sandia Engineering Reactor Facility was dismantled in 1969, when it was supplanted by the Annular Core Research Reactor that operated more economically in either a steady-state or pulsed mode. Sandia Pulsed Reactor II, followed by III, replaced the first pulsed reactor, and saw heavy use in studies of weapon vulnerability to neutron damage. In addition to Sandia's research, these reactors served Defense agencies and missile component contractors. Sandia's expertise in reactor safety brought new customers when the AEC space power and reactor groups requested assistance.

The significance of radiation effects on solid-state systems was reemphasized to both Bell Laboratories and Sandia in 1962 when the Telstar I satellite was disabled by the effect of the newly discovered Van Allen radiation belts on its power system and transistors. Although a major engineering effort managed to restore Telstar's operational capability, the lessons of radiation vulnerability were clear.

The ability of computers to model weapon effects interested Sandia as well. Don Morrison and the computer mathematics group pressed for greater computing capabilities, and by 1962 Sandia used its first computer simulation model for analyzing VELA satellite components. Although Sandia multiplied its computer capacity a hundred fold during the 1960s, it lagged behind its partner laboratories and even private corporations until the 1980s.

Computer models of the effects of x-rays on weapons became a major Sandia concern during the moratorium. Earlier missiles, such as the Nike series, had relied on neutron and blast damage to destroy incoming aircraft and missiles, but during the late 1950s the national defense community was concerned that above the atmosphere, x-rays from nuclear detonations in space might damage both missiles and space satellites. A program was started to measure and analyze x-ray effects and devise methods for protecting, or hardening, weapons, especially their electronics, against radiation damage. Carter Broyles, supervisor of the weapons effects department, received a personal citation from the White House for his radiation effects research.

In 1964, Walt Herrmann of MIT, formerly a consultant to Don Lundergan's shock dynamics group, was hired to start a new division to develop computer programs to aid in this analysis. He adapted his Wondy (1Dimensional) and Toody (2Dimensional) software programs into standard tools for analyzing radiation effects and developing hardening schemes.

The opportunity to conduct field experiments wherein a nuclear device was detonated to produce the desired nuclear radiation and blast environments to simulate enemy countermeasures was restored in 1962, following the 1961 Soviet break-out from the testing moratorium. Sandia's scientists and engineers became major players in full-scale atmospheric nuclear tests. Thus, weaponization engineers such as Vic Roh suddenly faced new, compelling testing challenges with essentially no warning or preparatory projects, and field test engineers became the critical coordinators of field operations for nuclear tests. Engineers in the weaponization project and systems groups designed, fabricated, and deployed a multitude of experiments at NTS that would expose weapon structures, components, and subsystems. Sensors coupled to the hardware being tested provided electrical signals to the telemetry instrumentation recording systems designed and installed by Sandia's field test engineers.

In 1961, Ron Snidow, a glass shop supervisor, applies final touches to a glass vacuum manifold fabricated for a Sandia research and development organization. Typical of the laboratory apparatus created by the glass shop, this piece demonstrates the skill required of the Sandia glassblowers.

Sandia's Shops

When Sandia began operations in earnest in the late 1940s, its engineers literally had to invent new tools, components, and production test equipment. Nuclear weapons were a brand-new technology and every new development was a voyage of discovery — and innovation. In addition, each new and unique component or tool designed by a nuclear engineer had to perform to the highest degree of perfection.

In part because this work was highly classified and in part because few machine shops around the country had the expertise to produce work to Sandia's exacting requirements, the Production Engineering group was created in May 1949, organized along Western Electric management lines. It was staffed during that first month by 12 men. A well-knit, efficient organization soon grew from the tiny nucleus. By November of that same year, when Sandia Corporation was formed to operate the installation for the AEC, Production Engineering was beginning to come into its own as a telling force, but it was woefully understaffed and swamped with a huge increase in its duties.

By 1951 it was a well-rounded organization of four divisions and fourteen sections with 137 employees, most of them experts in their fields. The Development Fabrication group, which had its origin in Manhattan Project days when the Army operated a small fabrication shop at Sandia base, boasted that it was equipped and manned to produce anything "from a wristwatch to a locomotive." Supremely confident of their unique abilities, these skilled craftsmen could make virtually any piece of machinery, tool, or electrical equipment upon request by any Sandia organization. Many of the tools, gages, testing and handling equipment, and even weapon components with which Sandia worked were first prototyped by Fabrication, and many designs were later turned over to other manufacturers for production in quantity.

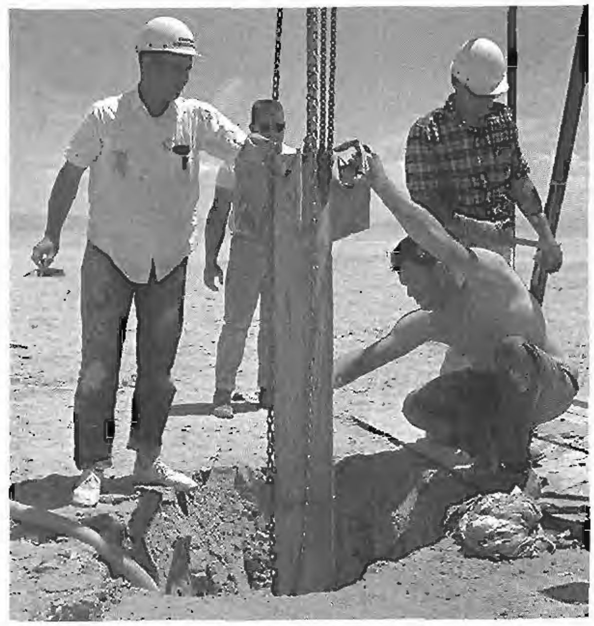
While new weapons were being designed and added to the stockpile, Sandia's specialized fabrication shops thrived and grew. However, by the 1970s, with fewer new weapons being designed, more off-the-shelf components available, and the concentration of Sandia's resources on research, the Labs' production engineering activities were greatly reduced. Much of the work was transferred to contractors. From then until the restructuring of the weapon complex in the mid 1990s, Sandia's production role consisted of small lots of items such as ferroelectric ceramics or microelectronics where new concepts and high reliability demanded close coordination between design and production. In the 1990s, the shops became known as the Manufacturing Technologies Center, a broad base of fourteen technologies which emphasized process development and focused on reducing the product realization cycle time.

EARTH PENETRATORS

Monk Schwartz encouraged Jack Howard, Don Cotter, and Leon Smith to explore new weapon concepts. Perhaps the most important of these moratorium-inspired explorations were the earth penetrator advanced development, the small multiple reentry vehicle (Pebbles/Halberd), advanced nosecone shielding, and permissive action link efforts.

Alan Pope, an aerodynamics expert at Sandia, and others originated the earth penetrator concept in 1960, when they considered streamlining a projectile so it would penetrate through the earth much as a missile plunges through the air. "Such projectiles could play havoc with underground missile silos," Pope predicted. When they initiated studies of penetrating weapons, Pope and Bill Caudle advanced a new science they named terradynamics, the study of the passage of shapes through geologic strata, just as aerodynamics involves study of the passage of shapes through the atmosphere. Through terradynamic investigations, they soon learned that the best ground penetration could be accomplished with projectiles shaped like a sharpened pencil, with plastic fins at the rear that sheared off when the projectiles entered the ground.

The original thought behind development of these earth penetrators was that they could put at risk missiles in silos or buried concrete command bunkers. Moreover, with a firing set that could survive the impact and then delay detonation until the weapon was beneath the ground surface, the weapon would be invulnerable to countermeasures after impact and nuclear fallout from the detonation would be reduced. Pope and his colleagues contended their penetrators, with shock-resistant telemetry transmitting through a trailing antenna, might also be used for quickly reconnoitering soil conditions for airfields, or for investigating subsurface geology in remote areas, even on Mars or Venus. After test impacts into granite, desert alluvium, clay, ice, limestone, concrete, and other materials, it became possible to chart profiles of the strata through which a penetrator passed by recording how the strata slowed a projectile.



Workmen hoist a Sandia earth penetrator from the ground. Analysis of the passage of these penetrators through soils and rock is a science developed at Sandia known as terradynamics.

During the 1960s, Sandia designed ice penetrators for the U.S. Coast Guard to test the depth and density of ice in the shipping lanes. Here, Jack Kiker assembles a penetrator for testing.

The Air Force thought the earth penetrator concept had merit, and in 1962 it agreed to jointly fund and cooperate in further development, especially of the use of research earth borers as dive bombs. However, the first use of Sandia's earth penetrator technology came during the Vietnam war when small penetrators dropped from aircraft were used to implant seismic sensors for detecting enemy activities. Several versions of nuclear and conventionally armed earth penetrators later were designed at Sandia, and conventional penetrators were deployed, some with striking effects, during the 1991 Persian Gulf War.

The earth surfaces studied for penetration were expanded over time to include ice and water in addition to rock and soil. In 1970, Wayne Young headed a Sandia team in Alaska adapting the penetrometers to study Arctic ice in the hope of providing a cheap and fast method of mapping routes through the frozen seas near the North Pole. Dropped from an airplane or helicopter, the penetrometer would provide information on the depth, hardness, and salinity of ice in an area before a ship was sent through.

Marlyn Sterk and Ron Johnson observe while Don Rigali, *kneeling*, describes an advanced nosetip test on multiple reentry vehicles.

PEBBLES/HALBERD

In May 1960 the Soviet Union demonstrated major advances in its surface-to-air missile capabilities by downing Francis Gary Powers' high-flying U-2. In addition to the serious foreign policy repercussions, this event heightened U.S. interest in developing missiles that could penetrate defensive systems. One such concept called for overwhelming defenses using decoys alongside real warheads atop missiles. As the inevitable measure-countermeasure discussions ensued, some analysts asked whether it might be possible to design actual warheads of size and weight comparable to decoys. The defense would then have to confront several small warheads rather than decoys that might be detected and ignored. Because this concept resembled throwing a handful of pebbles, rather than a single stone, it was code named Pebbles. Sometime later the code name was changed to Halberd, the name of a medieval battle ax.

A conceptual study of small reentry systems managed by Charlie Winter and Don Cotter was initiated in 1962 and Leon Smith chaired a committee to plan development of a reentry vehicle weighing perhaps a hundred pounds. The exploratory program was managed in a fashion resembling a standard weapon design phase 3, with competitive Sandia design teams in Livermore and Albuquerque and with Lawrence Livermore and Los Alamos each designing separate high explosive/nuclear systems. "Our goal," said Smith, "was to come up with an independently targeted warhead, small enough that it could be carried in multiples, with a yield that could not be ignored."

During the mid-1960s, Sandia teams achieved the goal of a light-weight, hardened, arming, fuzing, and firing system integrated with the reentry vehicle structure, and demonstrated this capability with a rocket test flight in 1966. Because such multiple reentry vehicles could substantially increase the effectiveness of each missile, the concept was presented to defense planners in both the Air Force and Navy.

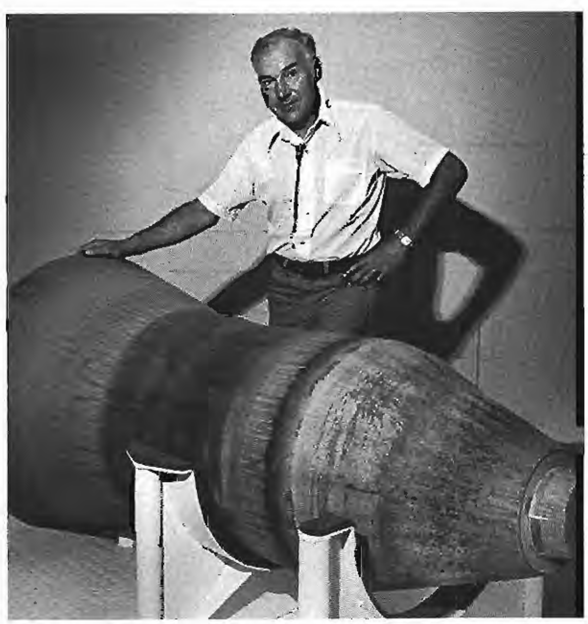
The fully integrated warhead and reentry vehicle concept raised a number of issues. There was opposition based on the 1953 Missiles and Rockets Agreement and some reentry vehicle contractors saw an integrated warhead as a significant cost issue. On the other hand, Secretary of Defense Robert McNamara recognized that deployment of multiple reentry vehicles could significantly reduce the requirement for silos for the land-based intercontinental Minuteman ballistic missile system. In addition, the fact that Sandia had already developed prototype hardware suggested to AEC management that new production work could quickly be funneled to its struggling Bendix facility in Kansas City. Finally, the Navy accepted the concept for its submarine-launched missiles, noting the promise of a substantial weight and volume savings. Also, the Navy's prime contractor, Lockheed, had responsibility for both the reentry vehicle and the missile system and so had far less to lose if an integrated warhead was chosen.

After an intense design competition, Sandia was selected by the Navy to design the arming, fuzing, and firing system for the Mark 3 reentry body to be carried on the submarine-launched Poseidon missile. During the negotiations, however, Leon Smith recalls a critical moment when the Navy and Lockheed requested control of the project's technical direction. Smith told them he was confident that Sandia could provide the arming, fuzing, and firing package if it was permitted to work within the AEC performance requirements with which it was familiar. However, if it were required to work within the unfamiliar Navy/Lockheed system, Sandia would, reluctantly, feel compelled to withdraw from the project. After a few tense days of consultation and discussion, it was agreed that Sandia could operate within the AEC framework.

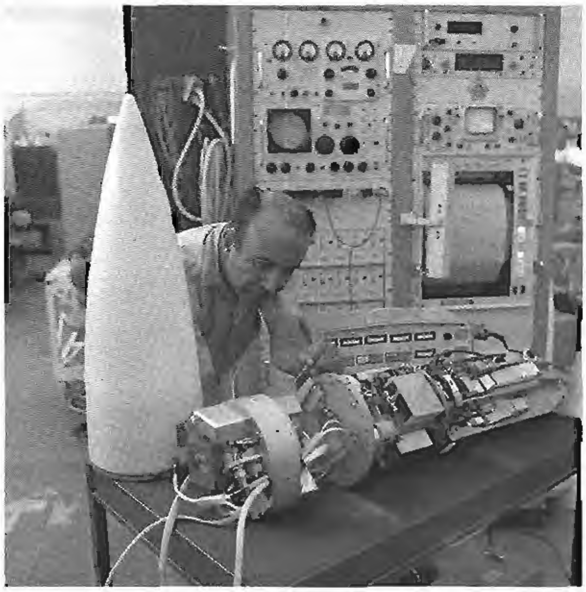
Overall, Sandia program management was provided by Glen Brandvold and his team at Sandia California, in collaboration with Lawrence Livermore, which was responsible for developing the physics package. Remarkable advances were incorporated in radiation hardening and gas transfer systems. Sandians in Albuquerque, designing their first complete missile warhead arming, fuzing, and firing package since 1953, were led by Bob Peurifoy and Gene Ives. Near the end of phase 3 development, because so many new concepts and advances had been introduced into the overall system design, Tom Cook took the unusual step of appointing Al Narath to lead a committee from the research organization to review critically every aspect of the design. Manufactured within the AEC integrated contractor complex, the system was an enormous operational success for the Navy, initiating a long-term relationship that Bob Clem described as the "largest reimbursable activity in the weapons area at Sandia."

REENTRY HEATSHIELDS

Sandia's interest in designs for missile reentry vehicles, or reentry bodies by Navy definition, generated another research initiative during the moratorium. Early intermediate-range missiles used metal heat sinks on reentry vehicles to absorb the heat generated during reentry into the atmosphere. By 1958, Sandia had begun its high-altitude research rocket design effort,



John McKiernan stands beside a recovered missile reentry vehicle. The heat of reentry into the atmosphere caused the visible ablation.



In 1966, Adolfo Martinez inspects a rocket nosecone package designed at Sandia.

and these had nosecones carrying diagnostics packages aloft. Sandia began investigations of heatshield materials that could provide the ablative protection needed for intercontinental missiles, while also hardening the vehicles against intercepts and reducing their image on defensive radar.

Dave Northrop led the carbon-carbon materials division, with Mort Lieberman studying the basic chemistry associated with the chemical vapor deposition of carbon, Barry Butler examining the micro and macromechanics of carbon-matrix carbon-fiber composites, Barry Butcher testing samples in the shock wave physics group, and Barry Granoff overseeing the manufacture and qualification of full-scale heatshields actually used in reentry tests.

The materials were made in Sandia's materials laboratory, in a carbon processes group headed by Eugene Frye, formed to investigate the use of carbon-carbon composites as ablative overcoats. Carbon, ranging from the slick graphite used as a lubricant and in pencils to hard diamonds, has unique properties, and Frye's team identified ways to use these in heatshields. They showed that wrapped carbon filaments in a carbon matrix became stronger at high temperatures and had inherent toughness, while also reducing x-ray induced stress loads resulting from enemy intercepts. They could also serve well for reentry heat shielding.

The materials work involved extensive teaming across Sandia. Northrop and Frye's divisions worked with the non-destructive testing and analysis groups, the thermal properties measurements group, as well as the shop, which pioneered methods of machining carbon, including full-sized heatshields.

Heinz Schmitt took charge of an exploratory systems development group to design a reentry body with a carbon-carbon reentry protection system, fabricating a few carbon heat shields and using Strypi rockets for the early flight tests in the Pacific. The Air Force joined in funding Sandia's nosecone research and the necessary proof flights, which continued into the 1970s. Harold Vaughn, Sam McAlees, and Dave McVey developed aerothermodynamic computer codes and conducted arc jet tests to predict the aerodynamics, aerodynamic heating, and ablation of these and later Sandia reentry vehicle heat shield designs. Ken Cole developed a three-stage rocket system TATER (Talos-Terrier-Recruit) to measure rain erosion of carbon-carbon and carbon-phenolic nose

Sandia during the 1960s developed prototype rocket nosecones of carbon. Chuck Thacker inspects one of these cones inside a furnace for chemical vapor deposition.

tips for the Air Force. TATER, which was faster than the Sprint missile, accelerated a 70-lb recoverable nosetip to 11,000 feet per second in 11 seconds. Don Shuster and Bob Peurifoy pointed to this program as pivotal in Sandia's history. Involving one of the first attempts to build maneuvering reentry vehicles, the nosecone program initiated the guidance and control development activities of Ron Andreas and Don Rigali that extended into the 1990s.

Sandia in 1960 developed the permissive action link (PAL) to prevent unauthorized use of weapons. This coding equipment is plugged into the PAL on a warhead.

PERMISSIVE ACTION LINKS

Sandia's concern for weapon safety resulted in further development of environmental sensing and handling devices to prevent accidental detonation. Later, Sandia developed permissive action links to prevent unauthorized detonation, thereby improving nuclear weapon system command and control. In response to concerns that nuclear weapons in Europe, particularly those with very small U.S. forces, might be used without approval from the President, Sandia and its partner laboratories studied ways to prevent the unauthorized use of weapons.

In late 1960, the Joint Committee on Atomic Energy, accompanied by Harold Agnew of Los Alamos, inspected installations in Europe and was disturbed by the state of command and control by the United States. Agnew was familiar with Sandia's advanced component development projects and suggested that one of them, the pulse-train environmental sensing device being considered for atomic demolition munitions, could be used to enhance use control. The Committee recommended to President John Kennedy that such devices, later called permissive action links (PALs), be installed on weapons deployed to Europe.

Presentations of the permissive action link concept by Jack Howard, Leon Smith,

Left to right: Air Force General Harold Donnelly; George Dacey; General Bernard Schriever; Kenner Hertford of AEC; Eaton Draper; and General John W. White, Commander AFSWC, meet in 1962 to discuss Sandia's weapon development programs.

Del Olson, and other Sandians to the military services initially were not well received. The military services considered the links another complication that might reduce readiness. Again, dual agency responsibility for nuclear weapons was essential because, despite these setbacks, Sandia pressed ahead with development of an electromechanical link. It focused on the concept of a switch that could be installed inside a weapon and remotely operated from a controller, making bypassing it difficult. This concept had its origin in the environmental sensing device (ESD) effort, where it was recognized that atomic demolition munitions encountered no unique or sensible environment. Thus, a "unique environment" was artificially created by the unique train of pulses that would activate the switch. With this design, a nuclear weapon could not be detonated until the President's order passed through command channels to an officer controlling the weapon system, who then ordered the code entered.

A Sandia task force under Leon Smith undertook expedited design and production of the first electromechanical PAL, a motor-driven device with wheels aligning in response to electrical signals from its controller. When the wheels aligned, electrical contacts were closed to allow the transmission of an arming signal. Charlie Winter described this design as equivalent electrically to that of a dial telephone: if the right numbers were not dialed in, it would not ring the weapon's arming system. The first PAL hardware was delivered to the Air Force in 1961 for installation in the W49/Jupiter system after a seven-month "crash" development program.

The Kennedy administration issued a memorandum in June 1962 mandating PALs for land-based nuclear weapons in Europe and authorizing continued research at Sandia. Working with the manufacturer, U.S. Gauge, Sandia delivered its first PALs to Europe in September 1962. In the meantime, Sandia created an organization to study ways to "hotwire" around, or defeat, the PAL. Gus Simmons became part of this first "blackhat" division at Sandia, which picked designs apart to find weak points, then shipped them back for redesign.

During the following decades, Sandia improved its PAL designs in several categories, changing from electromechanical to solid-state electronics and undertaking cryptographic research in conjunction with the National Security Agency for verifying code authenticity. "These have guaranteed that U.S. weapons could only be used under proper authority," declared component developer John Ford, proudly adding that the PAL became one of Sandia's "major contributions to worldwide security."

TECHNOLOGY SPINOFFS

From technology developments such as the environmental sensing device program came two of Sandia's best known early efforts to extend the benefits of its technology to private industry. One, the laminar airflow clean room, became an immediate and enduring success. The other, the rolamite, proved less useful to the private sector initially, although it found civilian applications years later.

"We had no idea of its significance at the beginning," said Willis Whitfield, speaking of the laminar airflow clean room he invented in 1960. At the time, he worked in Sandia's advanced manufacturing group, which included Claude Marsh, James Mashburn, Bill Neitzel, Longinos Trujillo, and others who sought means of removing dust from the air that might contaminate the close-tolerance parts required for the early piston-activated ESDs. An improvement on clean rooms then in use, Whitfield's clean room used a uniform flow of filtered air from the ceiling to the floor grates, or wall to wall, to remove dust from the air. Filters in the air stream not only stopped dust, they removed bacteria and fungi as well.

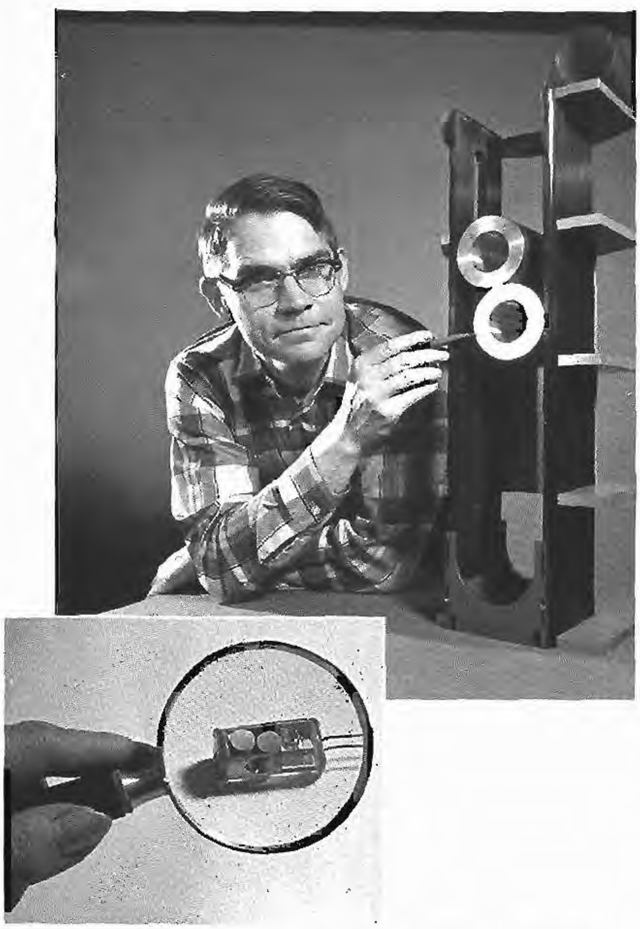
When Whitfield revealed his ultra-clean room development at a 1962 professional meeting, he was inundated by requests for information from industry and from Randy Lovelace, who adopted the clean room at his Albuquerque medical center for the protection of surgical patients. "It was a

Willis Whitfield of Sandia examines the ultra-clean room he invented in 1962. Because they could remove dust and bacteria from the air, clean rooms had many applications in the medical and microelectronics industries.

Top and right: Inside a Sandia clean room in 1965, Ed Powers of NASA and Vernon Arnold inspect the sterilization of an interplanetary lander.

revolutionary development," said Doug Ballard, supervisor of Whitfield's research group. "It was an improvement by thousands of times and there has been no basic improvement since then." Building laminar airflow clean rooms became a billion-dollar private industry, which has been credited with making the modern microelectronics industry possible. Applications were also found in pharmaceutical, food processing, and other industries where clean environments are important to quality.

One of the engineers involved in design of PALs and ESDs, Don Wilkes, invented rolamite, using rollers and a flexible band to serve as an inertial switch for weapons safing, and later incorporated in a variety of stockpiled nuclear weapons. Hailed as a new mechanism as basic as the lever, spring, or hinge, rolamite appeared to offer a simple solution for engineering applications such as relays, pumps, shock absorbers, bearings, and sensing devices. It had little friction, required no lubrication, and could be quite small and still serve its function. Rolamite excited the media and was even used by cartoonist Bill Mauldin to satirize two competing politicians revolving in opposite directions while moving the same way. Wilkes and several colleagues left Sandia to commercialize and market rolamite, with indifferent success. By the 1990s, however, the rolamite inertial switch found commercial application in the deployment of automobile safety airbags, among other purposes.

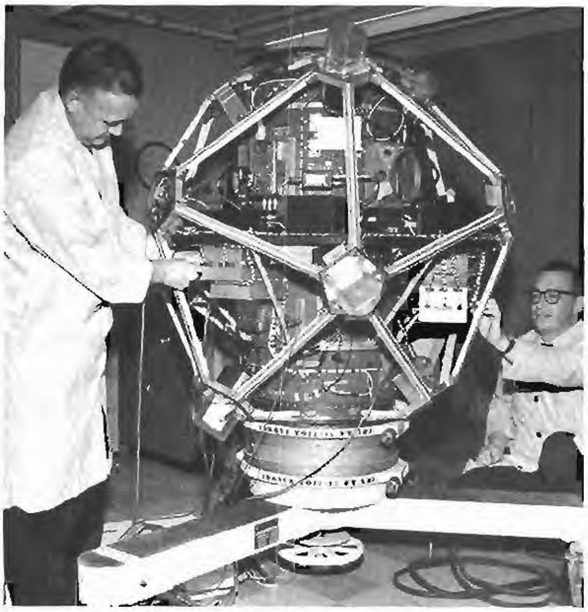


Donald Wilkes points to a large model of the rolamite switch he invented. The rolamite switch could be manufactured so small that magnification was needed to examine its workings.

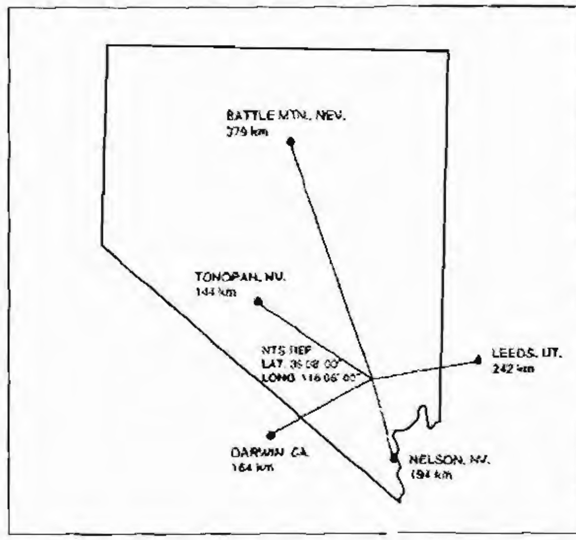
VERIFICATION

In addition to its rocket research, Sandia's role in space began in the VELA programs of the 1960s. Because of the desire to detect Soviet violations of the moratorium, the Advanced Research Projects Agency funded research in 1959 to verify Soviet compliance. Under the code name VELA, this first verification program took three tacks: the detection of secret testing in space, in the atmosphere, and underground. Los Alamos handled research on surface-based detection of atmospheric tests; Lawrence Livermore investigated subsurface testing; and Glenn Fowler and Don Shuster negotiated a role for Sandia both in the seismic detection of underground testing and, in a joint program with Los Alamos, to develop and install atmospheric and space nuclear-burst detectors and logic systems on Air Force space satellites.

Sandia entered seismic detection, the VELA Uniform program, on two levels. It performed research on interpreting seismic signals to distinguish between earthquakes and underground explosions, and planned a network of seismic stations to collect data. In 1960, Sandia's first seismic station near Albuquerque began recording earthquakes as far away as Japan, and a set of stations ringing the Nevada Test Site were soon opened. These stations documented the earth motion resulting from explosions at the test site,



Robert House and Simon Steely testing the payload for the first VELA satellite.

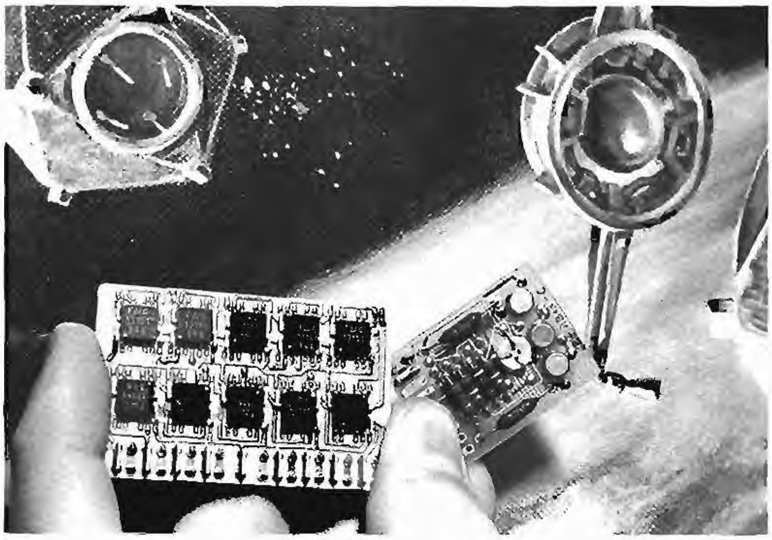


Stations in the Leo Brady Seismic System monitored underground testing from Nevada Test Site.

information useful when settling damage claims, and also created a data base for analyzing the differences between earthquakes and underground explosions. Sandian Leo Brady managed the NTS system for many years and, in tribute to his service, it became known as the Leo Brady Seismic System.

The VELA satellite technical management nearly duplicated that for weapons. Los Alamos designed detectors for detection of nuclear bursts in space. Sandia rocket systems with telemetry were used to assist Los Alamos scientists in measuring exo-atmospheric background data for neutrons and gamma rays to facilitate calculation of set-ranges for the detectors. Twenty-three flights were made from TTR and the Navy's Point Arguello facility. Instrumentation packages were also flown on Air Force and NASA rockets (Blue Scout Jr. and Ranger I) to acquire background soft x-ray data, but were unsuccessful due to launch vehicle failures. The Air Force provided launch vehicles and the satellite bus

Using the room-size IBM computers available during the early 1960s, Sandians developed computer simulation models for testing VELA satellite systems and radiation effects.



Solid-state electronics used in the VELA satellites held before an artist's sketch of the satellites in space.

including power supplies, thermal analysis and control, and communications systems; and Sandia designed the rest of the system. Later VELA satellites were launched with Sandia-designed optical sensor systems called bhangmeters, to detect nuclear bursts in the atmosphere. Management of this joint program with Los Alamos fell initially to a working group called the Buzzer committee chaired by Richard Taschek of Los Alamos and including Gus Simmons, Francis E. "Tommy" Thompson, Herbert M. "Brick" Dumas, and other Sandians.

"Transistors were still a relatively new thing," said Simmons, reflecting on the VELA design challenges. "And we were planning to fly something like an IBM computer in complexity. We had to do signal analysis in space." Simmons and the Sandia team shuttled back and forth to Washington, attempting to convince VELA planners that the logic system was feasible. "It was a hard battle," he recalled, "because no one had ever built a micro-miniature computer, which is what we were proposing to do, much less launch it into orbit."

When the VELA plans received full approval in early 1961, Sandia became responsible for logic and data storage systems, ground checkout equipment, and computer analysis of data coming from the detectors designed at Los Alamos. The schedule called for launching the first VELA satellites just eighteen months after the program started, adding great urgency to Sandia's research and development efforts. Later, James Scott of Sandia laconically observed, "A launch schedule is a great motivator."

To meet the VELA launch schedule, Scott and his colleagues marshaled all of Sandia's expertise in telemetry, power supplies, signal conditioning, radiation hardening, and materials sciences for this complex system: the original Sandia logics system for VELA contained 4,000 transistors, 10,000 diodes, and 34,000 resistors or capacitors. In a solar-powered, 50-pound package, Sandia had to design a logic system comparable to a room-sized IBM 704 computer that could perform in harsh launch and space environments, distinguishing natural radiation from nuclear bursts, collecting data and reducing it for transmission back to earth. For increased reliability and miniaturization, Sandia turned from vacuum tubes and wiring to solid-state semiconductor electronics and printed circuit boards. To check these components, Sandia, for the first time, used computers in a real-time mode to perform thousands of tests of the detection and logic systems over a wide range of simulated space environments.

Out of this effort came another Sandia technology spinoff, developed by Travis "T. A." Allen and Robert Sylvester, that soon transferred to the printed circuit-board industry. To complete circuits on printed boards, industry used unreliable soldering methods. To meet the high-quality standards for the VELA satellites, Allen and Sylvester invented hot-air solder leveling, pushing flux across circuit boards with hot air to prevent oxidation of the solder. Applied by industry, hot-air leveling in time became a billion-dollar-a-year business.

The first VELA tandem launch came in 1963, and by 1970 twelve of the satellites circled the globe. For this achievement, AEC chairman Glenn Seaborg issued his personal commendation to Monk Schwartz and the Sandia design teams headed by Bill Myre and Hubert "Pat" Patterson. Although designed only for six months of service, the satellites performed for years. The last of the twelve

Robert Sylvester and T. A. Allen examine the hot-air solder leveler they invented that revolutionized the printed circuit board industry.

was shut off in 1984, replaced by more advanced satellite detection technology. Not only monitoring for nuclear bursts, during their service they advanced science by detecting rare lightning "superbolts" and observing gamma-ray bursts from objects in deep space; indeed, the origin of the science of gamma-ray burst astronomy has been credited to the VELA project. At its end, Sandians labeled the VELA program a major success, because it took them further into high technology and brought similar assignments later that eventually helped reassure the United States and the Soviet Union that restrictions on nuclear testing could be adequately monitored.

SCHWARTZ AND THE END OF THE MORATORIUM

When Julius Molnar returned to Bell Laboratories in fall of 1960, his general manager, Siegmund P. Schwartz, took charge of Sandia. An electrical engineer from Lehigh University, Schwartz started his career as a lineman and exhibited such agility climbing poles that he earned the nickname "Monk" that followed him throughout his years with Western Electric and Sandia. At Western Electric, he supervised installation of phone service in many parts of the nation, including what he considered his most challenging job: wiring the Pentagon in 1942.

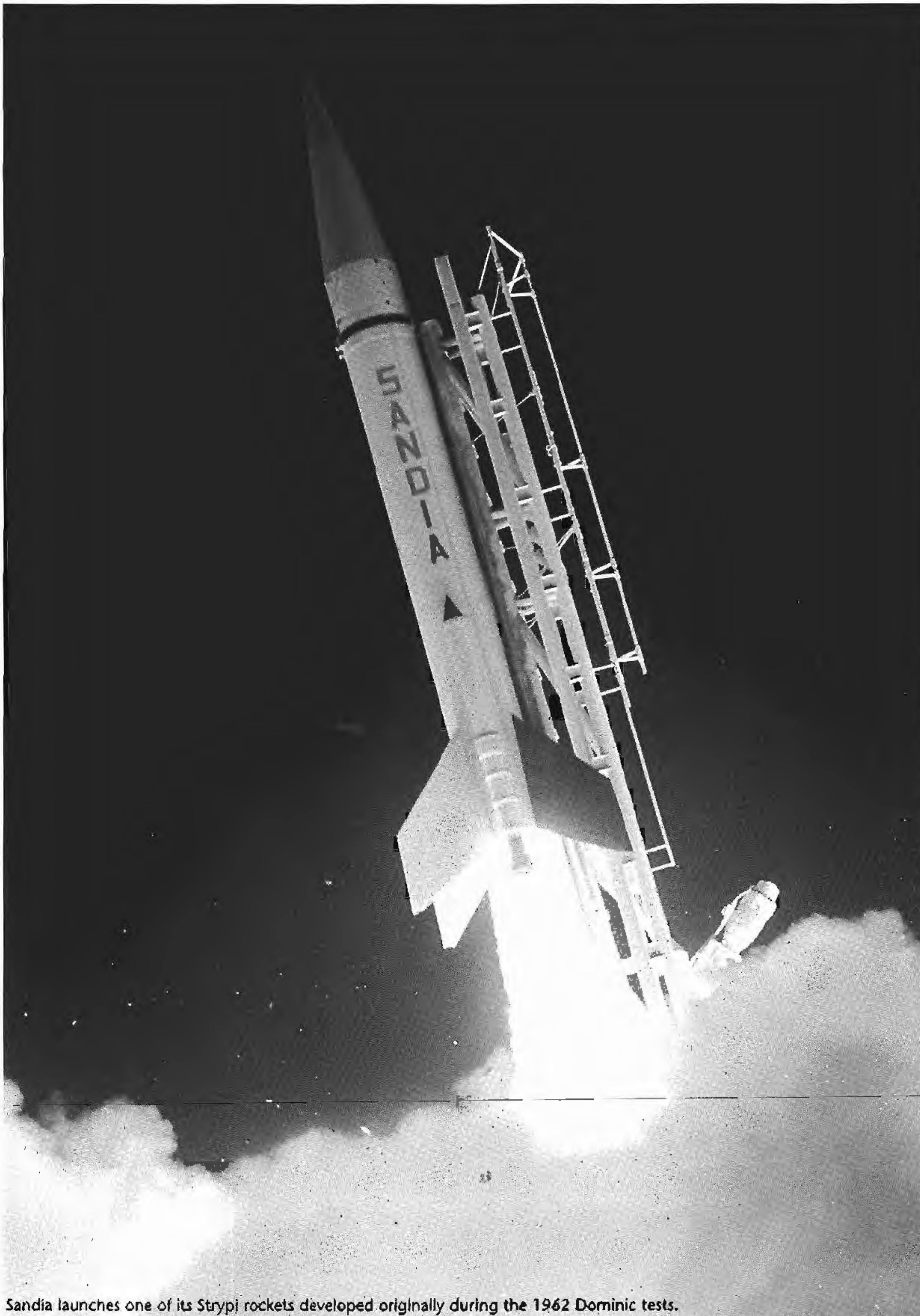
A detail-oriented manager, Schwartz personally conducted regular design reviews, calling project managers together to assess program status and budget. He therefore served as both president and his own general manager, calling on Robert Henderson, the vice president for weapon programs, to serve as executive in his absence.

As the 1958 testing moratorium extended into the 1960s, Henderson alerted Schwartz that members of Congress had begun to cast aspersions on the potential performance of the nuclear stockpile, because new weapons entering the stockpile had not undergone full-scale testing. John Kennedy's presidency brought even tighter controls on nuclear weapon programs.

In September 1961, the Soviet Union resumed nuclear testing, conducting an astonishing forty-five tests in two months. Of these, fourteen exceeded a one-megaton yield and one, tested on October 30, 1961, amounted to 58 megatons, the largest nuclear device ever detonated. The United States was not nearly so well prepared to resume testing. As Tom Cook later recalled: "We scrambled around in this country to bring the teams back together, start from scratch, and carry out the important nuclear tests the country needed. Caught flatfooted. That was a very busy year."

After thirty-four months of moratorium, in September 1961 Sandia prepared tethered balloons to serve as test platforms and to provide its traditional firing and diagnostic services at NTS. Thanks to Plowshare, seismic detection testing, and other programs, NTS had retained a viable organization for the resumption of testing in late 1961. For the atmospheric and high-altitude tests in the Pacific, however, a new task force had to be recruited and equipped for the Dominic test series of 1962.

Under General Starbird, commanding Joint Task Force 8, Don Shuster and his deputy, James Scott, managed the Dominic



Sandia launches one of its Strypi rockets developed originally during the 1962 Dominic tests.

program, while Cook and Clarence Mehl served as program scientists. Johnston Island became the Dominic operations base with Barber's Point on Oahu as an airdrop staging area. Sandia acquired part of the Barking Sands site on Kauai Island for launching diagnostic rockets.

Two of Sandia's main tasks in support of the air-drop portion of Operation Dominic were to provide instrumentation and data recording for the 29 missions and to provide the bomb-shaped vehicles containing the nuclear test devices, provided by either Los Alamos or Lawrence Livermore, to be delivered to the target by the specially configured B-52 aircraft. Because Sandia was involved in three major bomb design projects — the B43, the B53, and the B57 — it could draw on these programs to fill the needs of Operation Dominic. Assembly, test, and loading operations for the twenty-four air drops at Christmas Island and the five air drops at Johnston Island were staged from Barber's Point Naval Air Station near Honolulu, and began a mere six months after planning for Dominic was initiated. After air-drop testing was completed, a practical concern drove Sandia's efforts during Dominic's high-altitude tests — testing the effectiveness of antiballistic missiles by obtaining data on weapon outputs and effects at different burst heights.

The high-altitude Dominic tests, called the Fishbowl series, proved frustrating. When malfunctions forced the destruction of DoD missiles in flight and one on its launch pad, Starbird asked Shuster and Glenn Fowler to rush Sandia's development of a new rocket to carry warheads to the required height. Since Sandia had developed rockets powerful enough to lift heavy diagnostic packages, and had designed the warhead hardware for the earlier test launches, it accepted Starbird's challenge.

According to George Dacey, then vice president of research, Sandia named its new rocket the Strypi, referring to the striped tail of a tiger and implying that in accepting Starbird's challenge, Sandia had taken "a tiger by the tail." With thousands of personnel in the Pacific awaiting the next test launch, Sandia's development of the Strypi became urgent. Fowler said the schedule was "nearly impossible" and required working eighteen-hour days to meet; but, he pointed out with pride, his team designed, built, tested, and successfully fired the new rocket in less than two months. It carried a Los Alamos device to the required high altitude for detonation on schedule. The Strypi rocket proved so robust and reliable that it became a workhorse in Sandia's rocket research program, although it never again carried a nuclear warhead into space.

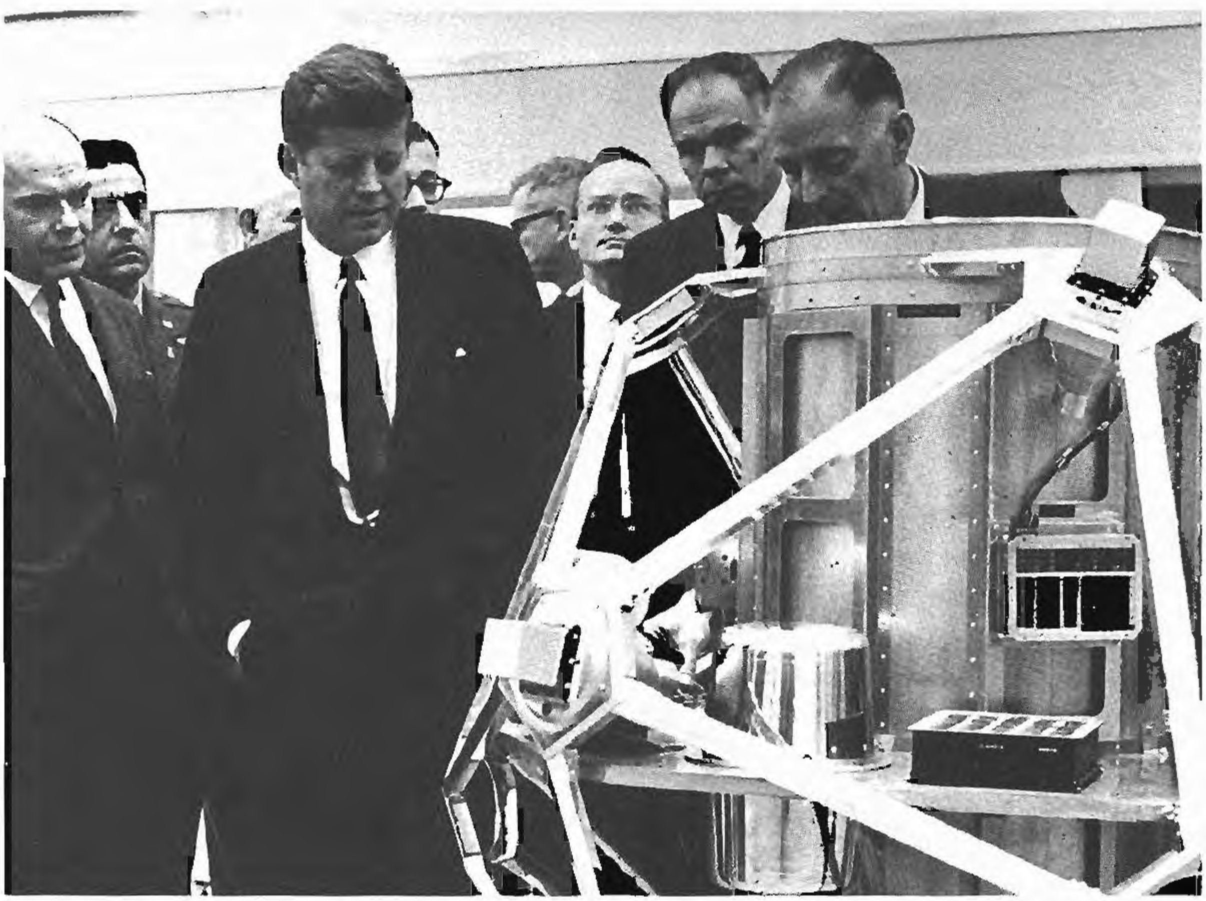
KENNEDY VISITS SANDIA

As the Dominic tests progressed, the Cuban missile crisis of October 1962 brought the world frighteningly close to a nuclear exchange. Sandia went on alert, coding its outgoing messages and overloading the coding facilities it then had. That month, Monk Schwartz visited Washington to report to Presidential science advisor Jerome Wiesner and the White House staff on the status of PAL development and overseas deployment.

Two months later, after tours of Strategic Air Command headquarters and Los Alamos, President Kennedy, accompanied by Wiesner, AEC chairman Glenn Seaborg, and a large official party, came to Albuquerque to visit Sandia. Arriving just after the end of the work day, the President received a rousing welcome from Sandians lining the motorcade route. While Schwartz gave the President a forty-five minute briefing on Sandia's weapons, PAL, and satellite verification projects, Robert Henderson and Glenn Fowler described Sandia's programs to others in the official party and the press. The most impressive event of the briefing, in Robert Stromberg's opinion, was the President holding and intently examining a PAL device, because "there stood the man who had the authority to unlock that coded switch."

In 1963 the United States and the Soviet Union completed negotiations for a limited test ban treaty suspending nuclear testing in the atmosphere, in space, and in the seas, thereby restricting fallout by confining

President John Kennedy and Senator Clinton Anderson entered Sandia in a motorcade on an evening in December 1962.



President Kennedy inspects the VELA satellite package designed at Sandia for the detection of atmospheric testing. Visible behind the satellite are national security advisor McGeorge Bundy, AEC chairman Glenn Seaborg and Sandia president Siegmund Schwartz.

Siegmund Schwartz, *right,* briefs President Kennedy, Senator Anderson, and AEC chairman Glenn Seaborg during the 1962 visit to Sandia.

testing to deep underground sites. In response to congressional concerns about Soviet abrogation of the treaty, the President enunciated four safeguards for the nation, which had been recommended by the Joint Chiefs of Staff to provide for: readiness to resume testing quickly in the forbidden environments if the treaty were violated, development of systems capable of detecting secret testing, aggressive underground testing, and maintaining the laboratory facilities and research programs necessary to "insure the continued application of our human scientific resources."

MORATORIUM RESULTS

Rather than the stagnation, reductions-in-force, and perhaps even closure feared in 1958, Sandia's initiatives assured its continued contributions to national security during the moratorium and afterwards. Sandia advanced on several fronts, adding accelerators, reactors, and new research laboratories to its facilities, improving both the capabilities and the opportunities for its work force, and establishing fruitful liaisons with the Air Force, Navy, and Advanced Research Projects Agency.

These initiatives later paid dividends in the form of reimbursable projects from the defense agencies for surveillance technology, earth penetrators, and reentry vehicle engineering. Supplementing traditional nuclear weapons design projects for the AEC, these reimbursable projects brought new programmatic stability. By the time of the signing of the Limited Test Ban Treaty in 1963, Sandia was no longer simply one of three AEC laboratories engaged in nuclear weapons design; it had joined in programs for enhanced use control, for arms control treaty verification, and for non-weapons projects.

"If there should be another moratorium, what would happen to Sandia?" research director George Dacey asked rhetorically in 1962. "Sandia represents a unique strength in the nation's armory," he answered, "and is one of the best of the laboratories which provide the nation with sound scientific judgment: to disband Sandia would be ridiculous."

This 1969 aerial view of Sandia, looking toward the southeast, shows the wooden structures built in the 1940s behind the tree line, with the brick structures of the 1950s and later in the background. Just behind the flag is Building 818, the first administration building.

IV

A DIVERSIFIED LABORATORY

Remember three things. We are spending hard-earned tax dollars that come not out of an inexhaustible tax treasury but out of the pockets of the American people; the fate of a nation may depend upon the excellence of the work of our team; the effectiveness of our team depends on our outside reputation.

Siegmund "Monk" Schwartz

The nuclear test moratorium of 1958 and increasing involvement in Southeast Asia led to new national security concerns for Sandia and the nation. Advanced development weapon programs generated capabilities that would pace weapon development and provide diversified program work through the 1970s.

President Kennedy and Secretary of Defense Robert McNamara tightly controlled new weapon delivery systems development. As Andy Lieber of Sandia later reflected, "It was an era of cost-effectiveness studies in the Pentagon, and the most cost-effective buy often was determined to be zero." As the number of phase 3 engineering development programs fell in concert with national security policies, Monk Schwartz and Sandia initiated efforts to acquire challenging assignments in special and reimbursable programs outside of nuclear weapons. With approval from the AEC, Sandia acquired new assignments in support of the NASA space mission and in conventional weapons technology. In support of the troops in Vietnam, for example, Sandia designed sensors for a proposed electronic fence between North and South Vietnam called "McNamara's Wall."

In a larger sense, the statutory safeguards attendant to the 1963 Limited Test Ban Treaty (LTBT) guided Sandia's activities during the 1960s. These safeguards were: aggressive underground testing of nuclear weapons; maintaining "laboratory facilities and programs in theoretical and exploratory nuclear technology which will attract, retain, and insure the continued application of our human scientific resources"; readiness to resume atmospheric testing on short notice; and developing surveillance systems to detect nuclear testing anywhere in the world. This effort was assisted, in part, by the AEC's continuation of level-of-effort funding at its laboratories.

Sandia's programs fulfilling these safeguards and its efforts to assure the safety of nuclear weapons and of power sources for space exploration brought it new expertise and increased public attention. By the end of the 1960s, it became officially known as Sandia Laboratories, although still labeled by *Popular Mechanics* as the "Super Lab that Nobody Knows."

UNDERGROUND TESTING SAFEGUARD

The first LTBT safeguard called for "comprehensive, aggressive, and continuing underground nuclear test programs designed to add to our knowledge and improve our weapons in all areas of significance to our military posture for the future." Responding to this mandate, Sandia's permanent staff at the Nevada Test Site (NTS) conducted technical studies; planned Sandia's role in device arming, firing, and diagnostics data collection; and supported the personnel coming from Albuquerque and Livermore for specific events. Bob Statler and B. G. Edwards were long-time leaders of Sandia's contingent at NTS, where they worked with the AEC Nevada office and its contractors.

Since the early days of nuclear testing, Sandia had provided arming and firing for test devices, both in the Pacific and in Nevada. Ed Jenkins and Bob Burton managed the arming and firing tasks from the 1950s until 1964, and Burton garnered media attention in 1957 when a device misfired and he and Forrest Fairbrother of Lawrence Livermore climbed a 500-foot tower to disarm it. Andy Max and Dick Petersen supervised Sandia's arming and firing division during the late 1960s, and Allen Church managed the team from 1970 until his retirement in 1994. (Church and his brothers, Ted and Hugh, sons of the Los Alamos Ranch School headmaster, lived on "The Hill" until forced out by the Manhattan Project in 1943. All three became Sandians.)

Sandia developed a strong interest in the containment of underground blasts, providing advisors to investigate this challenge, and installing sensors to measure the motion of ground shocks in the vicinity of the nuclear detonation. After one cavity collapsed as personnel were preparing to return to ground zero, the Sandia testing group improvised a monitor for ground vibrations by hooking a tube-type car radio to a Brush recorder. Sandians also participated in nuclear yield measurements, using for this purpose the amplitude of seismic waves detected by the Leo Brady Seismic System and a Los Alamos system called SLIFER (Shorted Location Indicating Frequency by Electrical Resonance). This technique was improved by Sandians John Brouillard, Dale Breding, Stewart Lyon, James Greenwoll, and Robert Bass to measure the advance of shock fronts emanating from nuclear blasts. With computers added for data analysis during the 1970s, both the SLIFER system and seismic yield measurements continued in use until the suspension of underground nuclear testing in the 1990s.

Sandians prepare for the 1963 Shoal underground test. *Left to right:* Wendell Weart, William Perret, John Eckhart, Paul Kintzinger, Ben Benjamin.

With the advent of renewed nuclear weapon testing after the moratorium, Sandia was called upon to provide ground motion measurements on a large number of underground tests, both at NTS and at off-site locations ranging from New Mexico, Mississippi, and Colorado, to Amchitka Island in the Aleutians. These field experiments were designed and analyzed by Bill Perret and Wendell Weart and fielded by the field test division.

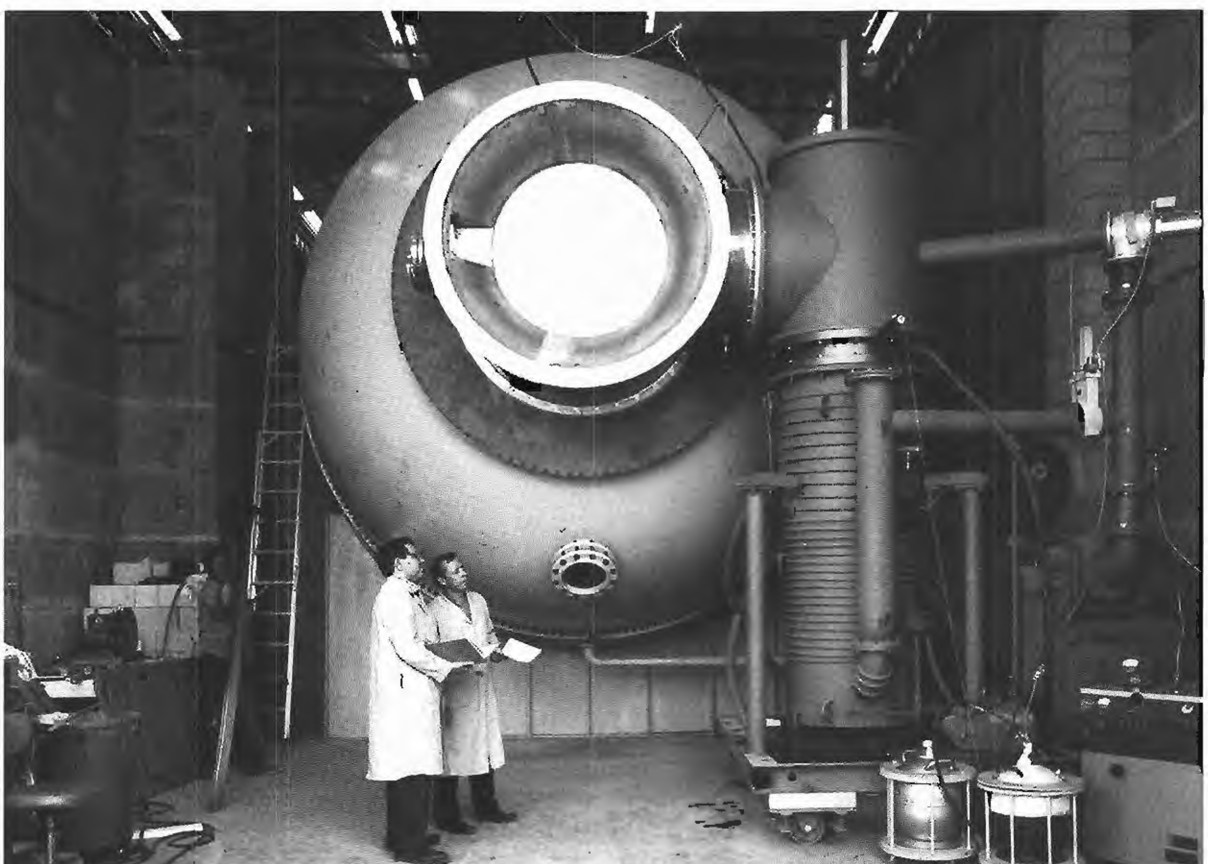
Sandia's experience with ground motion measurements resulted in a new role when test yields became large enough to raise concerns for safety and structural response in the high-rise buildings in Las Vegas. Weart served on the Nevada Operations Office (NVO) Ground Motion and Seismic Evaluation Subcommittee from the early 1960s until underground testing was terminated in the early 1990s. During the 1960s, Las Vegas resident Howard Hughes raised strong objections to the AEC's high-yield testing and Weart found himself representing the AEC's position in public hearings. John Banister directed the seismic motion contractors for NVO in the 1970s and 1980s during a period of extensive high-rise building response measurements.

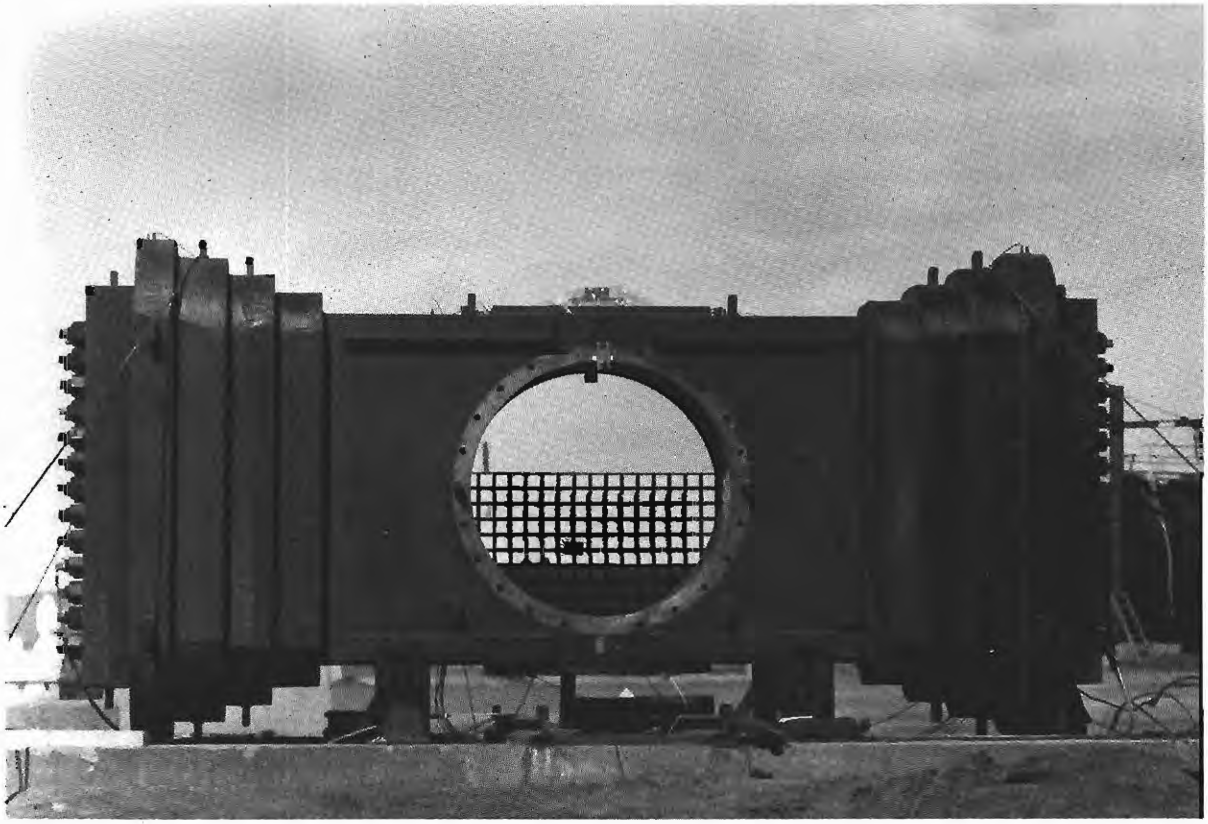
Jack Reed and colleagues provided blast and related predictions for the AEC Nevada office and monitored the recording instruments placed atop towers around the test site. Other Sandians were involved with the advanced drilling and logging systems for device emplacement bore holes at Yucca Flats, providing techniques for boring vertical shafts and tunnels for underground tests, and for cable transmission of data from the devices to trailers housing diagnostic and recording equipment. This experience proved useful during the 1970s when Sandia initiated its own drilling and logging research for its energy programs.

During the quarter century following 1963, Sandia participated in more than seventy radiation-effects tests, and when seismic and ground motion tests are added, the number climbs into the hundreds. Its testing activities differed, depending upon the purpose of each test and whether Los Alamos, Lawrence Livermore, or the Defense Nuclear Agency sponsored the test. Sandia itself was the AEC sponsor on three tests, Derringer, Cypress, and Camphor, conducted during the period from 1966 to 1971 to determine whether, for example, nuclear detonations caused x-ray and electromagnetic pulses that could damage warhead electronics.

Noteworthy among the technical advances that occurred during underground testing were the giant doors Bob Stinebaugh, John Weydert, and other Sandians designed to slam closed in milliseconds to contain nuclear blasts and prevent damage to the instrumentation packages. After neutrons,

Hermes II, a flash x-ray machine built at Sandia in 1968, performed more than 30,000 tests on materials and components before its operation ceased in 1990.





For underground testing at the Nevada Test Site, Sandia joined in the development of fast-action doors that closed pipes in milliseconds to protect experimental packages against nuclear blast waves.

gamma rays, and x-rays from a nuclear detonation passed through a line-of-sight pipe to the diagnostic packages, the doors were activated. These doors, later replaced by even quicker fast-acting closures, slammed across the pipe to prevent blast waves and high velocity debris from destroying the packages and their experimental data. These and related Sandia efforts in support of underground testing continued until the Comprehensive Test Ban Treaty negotiations began again in 1994.

Sandia president Schwartz briefs Vice President Hubert Humphrey during his April 1966 visit to the Labs.

SAFEGUARDING LABORATORY CAPABILITIES

With the number of new nuclear weapon projects declining, the question arose: how could Sandia implement the mandated safeguard for maintaining a vibrant laboratory capable of applying "human scientific resources?" Monk Schwartz responded during the early 1960s by exploring the application of existing Sandia competencies to other programs in addition to nuclear weapon engineering. This initiative was conducted within the AEC guidelines that any proposed reimbursable work for others should not require personnel or facilities increases, should not be subcontracted, and should not compete with the private sector.

During the space and missile race, the AEC collaborated with NASA and defense agencies in developing Systems for Nuclear Auxiliary Power (SNAP). This included research on nuclear reactors to power space exploration and on radioisotopic generators to provide lightweight and long-lasting power sources for satellites and deep-space probes. Los Alamos managed the Rover project for developing nuclear reactors to power spacecraft; Sandia provided engineering for the Rover experiments and in 1965 tested to destruction a full-scale mockup of a Los Alamos space reactor.

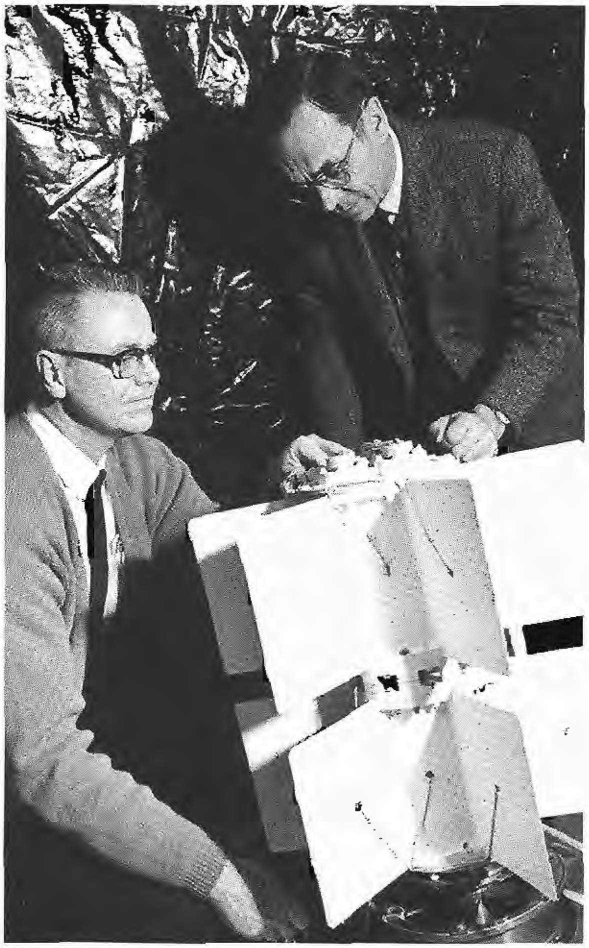
In addition, the AEC asked Schwartz whether Sandia would assess the safety of the radioisotopic thermoelectric generators and fuel capsules designed by Martin Marietta and other contractors for use as power sources in space satellites, navigation buoys, and at remote sites. Schwartz discussed it with Glenn Fowler, Bob Henderson, Dick Claassen, and staff, who thought the mission complemented Sandia's weapon research and VELA satellite programs. Schwartz then appointed Jim Scott, Tom Cook, Jim Shreve, Hubert "Pat" Patterson, and Hans "Ed" Hansen to draft the scope of work proposal to the AEC. "Because of their competence in obtaining an unusually high degree of reliability and safety in nuclear weaponry," announced AEC chairman Glenn Seaborg, "we have assigned the Sandia Corporation the task of making independent assessments of the safety of all our nuclear aerospace systems."

Sandia's early mission in the SNAP program involved testing and analysis to assure that plutonium or other radioisotopes fueling the thermoelectric generators would survive the launch environment or accidents. To accomplish this, Sandia formed an

Jim Jacobs, Arnold Bentz, Arthur Clark, and Bill Everhart examine a SNAP reentry vehicle.

In 1966 Glenn Fowler briefed AEC chairman Glenn Seaborg on Sandia's SNAP and reentry vehicle testing programs.

In 1965, as part of the SNAP program, Dave McVey and Ken Touryan in the plasma jet laboratory study how the heat of reentry could be converted into power.



After an impact test, Robert Luikens and Vincent Redmond examine a SNAP 19 designed by Martin Marietta Corporation.

aerospace nuclear safety group managed initially by Alan Pope, Vern "Gene" Blake, Ed Hansen, Arthur Clark, Edward Harley, and Arnold Bentz. In Sandia's environmental test area, they burned, smashed, heated, froze, and drove capsule prototypes into water, assessing capsule strength and advising contractors of any weaknesses detected. Aerodynamicists Randy Maydew and Harold Vaughn modified a wind tunnel to simulate high-altitude conditions for reentry vehicles, and Sandia added a high-enthalpy arc tunnel to subject power supplies to supersonic winds and high temperatures at the same time. Sam McAlees developed aerothermodynamic codes to predict burnup of the SNAP systems on reentry. Meanwhile, Shreve, John Banister, and others investigated and modeled the dispersion and fallout of radioisotopes reentering the upper atmosphere.

A highlight of SNAP safety work came in 1963 and 1964 when Sandians conducted two reentry flight demonstrations. Carried aboard NASA rockets from Wallops Island, Virginia, mockups of SNAP models traveled 800 miles downrange before reentering the atmosphere near Bermuda. William Everhart served as the Sandia operations manager at Wallops Island, while field test project engineer Don Beatson and a large team of other Sandians on Bermuda monitored the fiery reentry with telescopes, tracking cameras, and telemetry to collect data on the performance and safety of the vehicles and mockup capsules.

In addition to furthering Sandia's developing capability for reentry vehicle aerodynamics design and testing, the SNAP program produced advances useful for military missiles and environmental research. Murphy Landry and Sandia's instrumentation division, for example, developed a sensitive laser radar to detect particles eroding from the SNAP and nosecone during reentry. They reported that this system also might be used to monitor particles polluting the air over Albuquerque and urban areas.

Sandia's safety assessments for SNAP were so well received that in early 1966, when the AEC transferred SNAP program management from its New York to its Albuquerque office, Sandia became responsible for technical administration of the entire program. This included not only safety assessment, but also technical design review, environmental field testing, and quality evaluation of contractor production, plus research on advanced isotopic generators. Arthur Clark and John McKiernan managed Sandia's design and quality reviews of the work of seventeen SNAP contractors, while Bob Stromberg and Read Holland investigated advanced isotopic systems. The latter included investigations of radioisotopic thermoelectric generators, which converted the heat from radioisotopic decay into electricity. These early thermoelectric studies proved useful years later, both in nuclear weapon work and as interest grew in space voyages to Mars and beyond.

A spectacular event in Sandia's SNAP program came in 1969, when Apollo astronauts became the first humans to walk on the moon. The astronauts deployed SNAP units on the moon with Sandia-designed seismic detectors to monitor moonquakes, adding substantially to knowledge of lunar geology.

Schwartz also created an advanced systems studies directorate led by Don Cotter to perform initial studies of promising future areas of research and development. This directorate was administered differently from the rest of the line organizations at Sandia so that its mission of creativity and innovation would be supported. The director reported directly to Schwartz and the directorate, purposely kept small and select, consisted of staff members, section supervisors, division supervisors, and other managers, each person reporting directly to Cotter himself. This organization was successful at initiating new programs in small, hardened reentry vehicles; advanced use control hardware; and code management concepts. In addition, it was instrumental in the acquisition of the Mk 3 reentry body/Poseidon arming and fuzing system design and the planetary quarantine and Joint Task Force-2 projects.

The Planetary Quarantine Program had been suggested by the National Academy of Sciences in 1958 as a way to assure the ecological preservation of planets and natural satellites other than earth during the exploration of space. Sandia's clean room expertise was applied by Cotter's group to gain an assignment from the Planetary Quarantine Department of NASA Headquarters in 1966. The resulting Sandia study set the pattern by which international standards of planetary quarantine were established. Willis Whitfield, along with Jacek "Jack" Sivinski, Virgil Dugan, Marcel Reynolds, Charles Trauth, and other Sandians, took part in this planetary quarantine study aimed at sterilizing spacecraft before their launch and again upon their return from space. Dugan developed a vacuum probe sampler that could assay microbiological surface contamination, and the team learned that sterilization of space vehicles could be best accomplished through a combination of dry heat and irradiation. Thermoradiation, they observed, might be effective as well for the sterile production of pharmaceuticals, medical products, cosmetics, and foods, and a decade later they received funding from the Environmental Protection Agency for studies applying thermoradiation to sewage sludge.

The laboratory capability safeguard was further supported by a 1960 AEC decision to fund the laboratories on a level-of-effort, rather than a program-by-program, basis. The commission noted that "discontinuities [caused by] sudden elimination or the drastic curtailment of a single activity can have serious effects on apparently remote programs since frequently the value of a staff group is not confined to the activity which provides its principal support." The decision to implement level-of-effort funding introduced a stability into the program that facilitated orderly movement from one program to another. At the same time, the laboratory maintained its ability to quickly shift sufficient resources to high-profile "quick starts," such as test resumption in Operation Dominic. The Lab's budget usually was not increased when a new program was added.

THE READINESS SAFEGUARD

Drawing a concrete historical lesson from the 1958-1961 moratorium, Congress in 1963 mandated that the nation should stand ready to promptly resume testing in the prohibited environments when national security required. Responding to this specific safeguard, the Air Force formed a special unit at Kirtland with aircraft ready for nuclear testing at any time. Part of Sandia's readiness role involved modifying three aircraft to serve as diagnostic platforms, designing test vehicles to carry the devices and telemetry for nuclear tests, and participating in readiness practice missions, often in connection with scientific research projects.

Working with its partner laboratories and the Air Force, Sandia enlisted the aid of several contractors and prepared instrumentation to be installed in three C-135 aircraft, thereafter designated as NC-135s. Each of the aircraft was devoted to one of the three weapons laboratories. Los Alamos was

BUYING FOR THE THOUSANDS

Jeanne Jolly explains purchase order terms to Gloria Gonzales while Betty Sherred tabulates information at the next desk. The three were part of the invoice processing assembly line that guaranteed prompt payment of Sandia's commercial suppliers in 1962.

Purchasing

It takes a lot of material, ranging from the ordinary to the astonishingly extraordinary to keep an operation as large as Sandia running from day to day. Over the years, Sandia's workers have used the usual office supplies of reams of paper, piles of paperclips, and stacks of diskettes, as well as a variety of specialized technical equipment. Most of these items were bought on the open market from established suppliers of goods and services. Some purchases were straightforward, of course, but much of Sandia's specialized equipment and parts have been designed by the Labs' technical staff and manufactured specifically for it. Arranging for the supply of all of Sandia's needs is the responsibility of the Purchasing organization.

When Sandia was still Z-division of Los Alamos, most of its purchasing was handled by the University of California. Henry Moeding was Z-division's procurement representative beginning in 1946 when there were only about 100 people employed by the University of California at Sandia Base. Until 1949, when Sandia Corporation was formed, Moeding sent all purchase requisitions to the University of California Purchasing Office in Los Angeles and the buying was done there. After the management contract changed, however, Sandia handled its own purchasing, albeit under the guidance of a manager transferred from Western Electric.

Purchasing has been responsible for meeting some tight deadlines on crucial projects in addition to supplying the day-to-day operations of the Labs. For example, when the Soviet Union began nuclear testing again in 1961 after a 3-year moratorium, Sandia was plunged back into active field testing. Like everyone else at the Labs, Purchasing was stretched to the limit. Ed Herrity, who was the Division Supervisor of the group buying for full-scale testing, depicts a hectic, but successful scramble to get everything done:

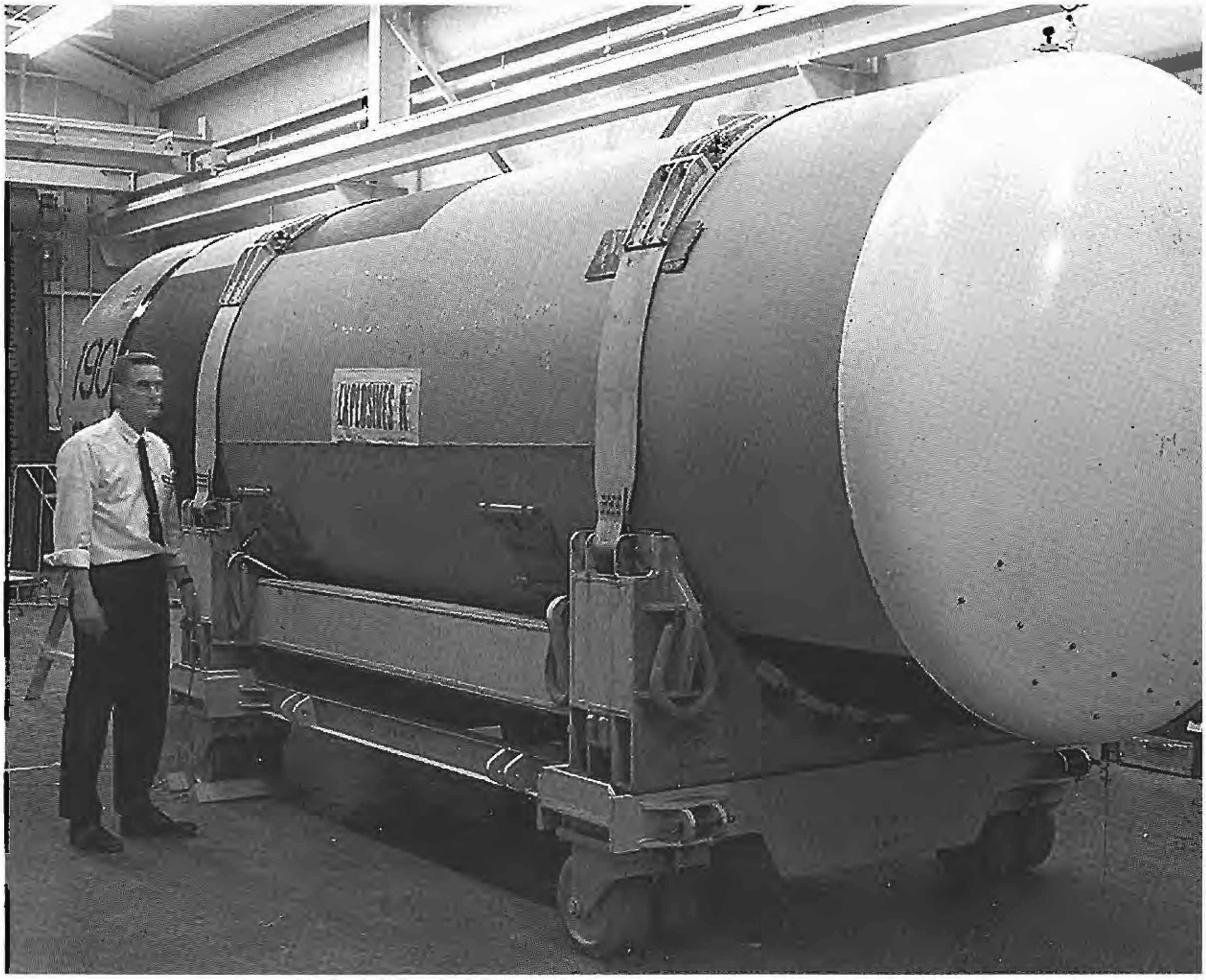
And we went all out and did get all the equipment on time ... I devised a system of rewards and penalties. If you delivered early you [the supplier] got more money. If you delivered late, you were penalized so much a day and during that period people were in airplanes putting the things together flying into Sandia to deliver on time. But it was very hectic, lots of fun. We worked 60, 70, 75 hours a week with 8 hours overtime paid.

After the success of the first full-scale test, Purchasing's effort was recognized in letters of commendation from Vice President of Field Test Glenn Fowler and Sandia President Monk Schwartz.

The mass of paperwork required to sustain a successful Purchasing operation was done manually until the late 1960s. At that point, a new typing pool was formed under the supervision of Oleta Morris to centralize the paperwork effort. The women worked with Western Electric teletype machines that allowed them to use templates for the different types of supplies ordered. This increase in efficiency was further bolstered in the early 1970s when Purchasing shifted to a computerized operation.

Different approaches have been taken to ordering and providing supplies to Sandians over the years. One of the biggest changes in this area occurred in the mid-1980s when Sandia completely altered its purchasing philosophy, moving from commodity to organizational buying. In 1949, Sandia had set up an in-house storage facility known as General Stores to carry an inventory of stocked items in addition to a large number of non-stock items purchased for particular jobs. This system worked very well over the years, but eventually began to show the strains of maintaining a centralized system for a large, diversified workforce. The inventory was large and often out of date, orders for new and specialized items were slow to be delivered, and there were complaints about product quality.

In 1983, Purchasing division supervisor Katherine Danforth chaired a committee to analyze the overall procurement situation. The committee concluded that efficiency and customer satisfaction could be increased by moving to systems contracting, in which Sandia would agree to buy a line of items exclusively from one vendor in exchange for the vendor's guarantee that the items would be stocked and delivered as needed. Authorized in 1984 and known as Just-in-Time, this purchasing system allows procurement to focus on the needs of the individual organizations, going beyond an exclusive concern with the lowest price to an emphasis on finding the best product for the job.



In 1969, Herb Filusch stands next to a big test vehicle (BTV) banded to an S212 bolster and loaded onto an S289 dolly.

assigned Tail Number 369, Sandia 370, and Lawrence Livermore 371. Lee Hollingsworth, William T. Smith, and John Eckhart managed the readiness effort, which included the aircraft modifications and participation in the early test exercises, while Arthur Cole directed the design of universal and specific test vehicles (ballistic shapes with arming and fuzing systems) that could be tailored to house test devices of various sizes and shapes to facilitate their release from B-52s for detonation at the required test altitudes. Among these were a tamarin test vehicle (TTV) for testing contact bursts at water impact, an electromagnetic pulse test vehicle (EMPTV), the big test vehicle (BTV) for the largest devices, and a universal test vehicle (UTV) for a variety of devices. Sandia tested this equipment, minus any nuclear explosive devices, during training exercises.

Sandia regularly joined teams in test exercises, usually at the Pacific range, throughout the 1960s. Their purpose was to validate and verify that air drop hardware, procedures, and personnel had achieved and/or were maintaining the required state of development and readiness to test. When such an exercise began, Al Huters and a crew flew with the Sandia NC-135 to the site, and Joe Stiegler provided engineering coordination for other Sandians who operated ground tracking telemetry. Under joint task force command, the readiness exercises became massive operations. One hundred and ten Sandians went to the Pacific, for example, during a 1964 test exercise, and 170 participated in a 1967 exercise. As part of its readiness posture, Sandia continued to operate the Barking Sands rocket-launching facility on the island of Kauai in the Hawaiian chain as well as

Sandia's crew examines a map while preparing for a 1967 scientific expedition in the readiness aircraft shown in the background. *Left to right:* Robert Martin, Sanford "Sandy" Markowitz, Raymond Caster, Merton Robertson, Roland Hewitt.

retaining the capability to launch diagnostic rockets to obtain high-altitude test data. Barber's Point Naval Air Station was used for final assembly of test devices and as a staging area for B-52 drop aircraft.

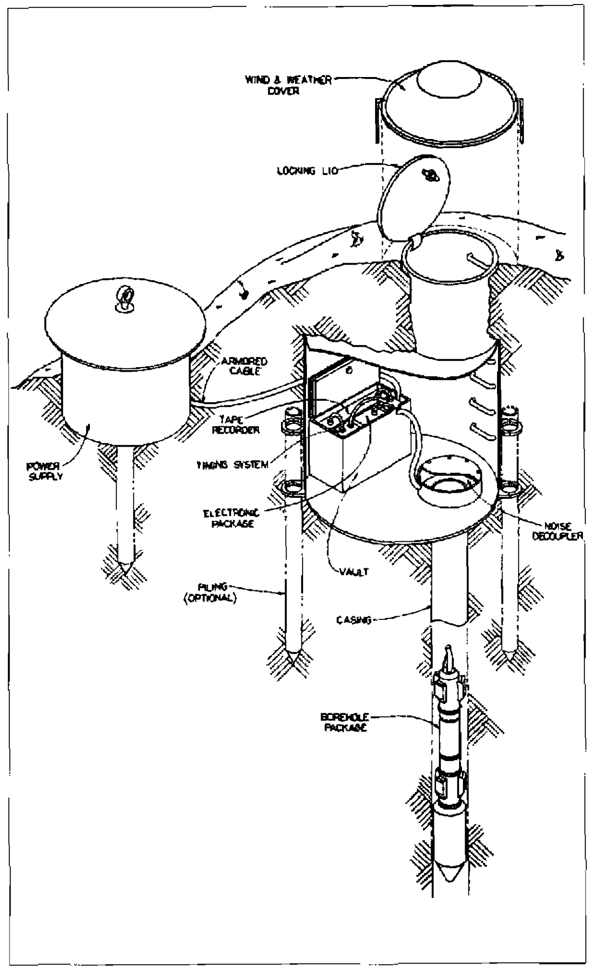
To multiply benefits from the readiness program, Sandia's diagnostic aircraft and crew frequently joined in scientific research. During solar eclipses in 1965 and 1966, for example, they followed the eclipse shadow to points around the world, carrying instruments to examine the sun's corona and the interactions of solar gases with the earth's atmosphere. In 1970, with Merton Robertson as scientific director, they flew to the North Pole with spectroscopic instruments to study the aurora borealis, identifying the energy sources and the subatomic particles providing the energy transfer. Scientists considered this research especially useful because the diagnostic aircraft could fly above the dust and atmospheric disturbances that hampered ground-based observatories.

In addition to readiness to resume air-drop tests, Sandia also began a concentrated effort to develop the capabilities and tools for the conduct of high-altitude tests and instrumentation, which had been meager, at best, in the 1962 series. A family of instrument-carrier rocket configurations based on a new upper-stage rocket motor was designed and qualified. The new motor provided greater payload volume and weight capabilities for loft to much higher altitudes. Associated efforts produced reliable water recovery systems with location aids to enhance probability of location. Radiation-hardened instrumentation, airborne tape recorders, and telemetry subsystems were also developed.

A new family of Strypi variants was developed and flight qualified to lift candidate devices to the required test altitudes and positions. Two single-stage and one two-stage configuration were qualified. Adequate quantities were produced and placed in storage for use in any resumption of test activities. The ground preparation, checkout, and operational capabilities at Kauai and Johnston Island were expanded and upgraded. Test launches of the instrumentation and device carrier rockets were regularly conducted at Johnston Island, while instrumentation rockets were launched from Kauai. Eventually, coordinated efforts were conducted at both sites to incorporate Joint Task Force command, control, and communications activities and to validate other AEC laboratories' involvement.

As development of these capabilities matured, new missions were sought to challenge and exercise the assigned personnel. Solar x-ray experiments were flown for Los Alamos and stellar x-ray experiments for Lawrence Livermore. The Strypi rocket family was expanded to include three-stage versions for test of reentry vehicle systems and subsystems, and was instrumental in Sandia's ability to develop and demonstrate maneuvering reentry vehicles and the recovery of high beta reentry vehicle nose tips and heat shields.

These readiness projects continued for nearly a decade. Staunch weapon program advocates in Congress eventually turned to more pressing matters, however, and readiness lost most of its funding. In 1975, the readiness program was redefined to a narrower scope and further reduced in size.



Sandia's 1963 plan for unmanned seismic observatories, used for verification of underground nuclear testing.

SURVEILLANCE SAFEGUARD

In order to meet the mandate for "developing surveillance systems to detect nuclear testing anywhere in the world," work on the satellite-based and seismic monitoring systems, discussed in the previous chapter, was continued and expanded. Work on the VELA satellites was devoted to improving the components. The satellites were launched in pairs and separated once they were in space. In all, six pairs were launched. For the last three pairs, Sandia developed optical sensors to enable VELA to detect nuclear detonations within the atmosphere as well as in space. The last pair of satellites was launched in 1970 and finally turned off in 1984.

In addition to VELA Hotel, the satellite program, the Advanced Research Projects Agency (ARPA) also sponsored VELA Uniform, a program to detect underground nuclear detonations by identifying their seismic signals. The electronic techniques initially developed for the VELA satellite program were also adapted for use in the Unmanned Seismic Observatory (USO). In 1964, ARPA authorized Sandia to begin a program to design, construct, test, and evaluate a prototype USO. The USO was designed as an aid in detecting, locating, and identifying seismic events. Capable of operating unattended for up to 120 days, the USO continually recorded seismic data to be retrieved and studied later.

Under the supervision of Charles Scott and then Brick Dumas, Sandia's seismic

Dean Gladow lowers Sandia's seismometer package into an unmanned seismic observatory, used to monitor underground nuclear testing.

systems section had a design ready for prototype production in 1965. The first of the units was installed in Alaska in 1966. Later that same year, a unit was placed in Utah and one in the Manzano Mountains near Coyote Canyon in Albuquerque. A test period extended through 1967, with project leader R. Stanton Reynolds and his team evaluating the USO's operation in the climatic extremes provided by the chosen sites. The USO proved a lightweight, rugged, reliable device that was relatively easy to ship and install. As will be discussed later, it eventually was replaced by newer designs, but the goal of seismic detection of underground nuclear bursts remained unchanged.

THE B61

From the end of the moratorium until 1970, Sandia had far fewer weapons to design than during the 1950s. Indeed, it and its partner laboratories had but one new bomb design — the B61. It was on a Saturday morning in November 1962 that Charles Carpenter announced to members of the Sandia team that they had a new program to design a lightweight tactical thermonuclear bomb. Authority to proceed with phase 3 development engineering came formally in March 1963, and a project division was formed, consisting of thirty people and soon increasing to eighty. Carpenter managed the B61 project, with John Tenbrink as lead electrical engineer and John Postlethwaite as lead mechanical engineer.

Design of this full-fuzing option, multipurpose bomb provided for laydown delivery at low altitudes by high-speed Air Force and Navy aircraft, and multiple carriage by Strategic Air Command bombers. The design team tested both aluminum and steel casings for the bomb, settling on aluminum after they learned that the steel casing resonated at impact, severely shaking the bomb's inner components. Like the B57, its ribbon parachute (designed by Bill Pepper) was deployed aft by a telescoping tube. However, because the B57 tube sometimes tore the parachute during its ejection, it was redesigned for the B61 with a device patented by Bob Grover to arrest the tube before it ripped the parachute. To further mitigate the shocks attendant to laydown on hard surfaces, Sandia added cushioning in the form of plastic foam.

Electrical connectors on earlier bombs had been a common source of difficulty, especially when their pins became misaligned

A B61 modification ready for testing on Sandia's rocket sled track.

and caused electrical shorts. Jim Cocke and Ray Reynolds were responsible for redesigning these connectors and supporting the electrical system of the B61, while George Duke designed a transistorized converter firing set.

The B61 design required extensive field testing to assure compatibility with twenty-two different kinds of aircraft, and these tests revealed an unstable trajectory upon release at high altitude. To overcome this, the engineers added a spin rocket to rotate the bomb and provide the required stability as it fell to target.

As the original B61 design neared the production phase, pressures on the design team increased, and Carpenter suffered a fatal heart attack. Oscar Fligner then took charge of the B61 project and completed its original design. In later years, Charlie Burks managed the modifications made to the basic B61 design to add new safety and use control features along with other capabilities.

Many of Sandia's later advanced system development projects used the B61 as a building block in novel configurations as a depth bomb, as a missile warhead, or as an extended range bomb. According to Burks, the rationale was that the use of existing designs would minimize development costs and time, preclude the necessity for testing new nuclear packages, and reduce the impact on the AEC production complex.

WARHEADS FOR NEW WEAPON SYSTEMS

In 1962, a Nike-Zeus missile brought down a target reentry vehicle, introducing the possibility of intercepting a single intercontinental ballistic missile. In 1964 Secretary of Defense McNamara approved deploying multiple independently targeted reentry vehicles. Ballistic and antiballistic missiles received top priority throughout the 1960s, as reflected in Sandia's weapon engineering programs. Sandia performed engineering development with both Los Alamos and Lawrence Livermore for warheads carried by the Minuteman and Titan intercontinental ballistic missiles and the Navy's submarine-launched ballistic missiles, moving on during the late 1960s to the Sprint and Spartan missile warheads for the antiballistic missile weapon system known as Safeguard.

Minuteman ballistic missiles were deployed during the 1960s. Sandia's portion of the joint Sandia/Los Alamos Minuteman warhead (W59) came under the management of John McKiernan, Oscar Fligner, and Reynolds Moore, and lead engineers Louis Hansche, Tom Edrington, and James Leonard, who also worked on a W59 adaptation, the short-lived Skybolt missile warhead that President Kennedy canceled in 1963. Elwood Ingledue and a project group including Dick Craner, Arnie Rivenes, and others designed the W56 warhead systems that were deployed on Minuteman and, later, on Minuteman II. In 1964, Roger Baroody and Ralph Cozine managed the project team for Sandia Livermore's Minuteman III (W62) warhead design.

In 1965, to test missile warhead system components for their vulnerability to blasts from enemy antimissile systems, Sandia opened Thunder Range in Coyote Canyon, south of its main technical areas. It had reusable steel shock tubes named Thunderpipes, one-shot plywood structures called Thundertubes, and steel-lined boreholes in the ground dubbed Thunderwells. High explosives detonated at one end of these sent blast shocks through the pipes or tubes to strike the components under test at the far end. Explosions rolled like thunder across this range as Sandia tested components for both the Bagpipe advanced development project and the Sentinel and Safeguard antiballistic missile systems.

In 1967, President Lyndon Johnson's approval of the deployment of the Sentinel antiballistic missile defense system called for replacing the Nike-Ajax missiles ringing some

Sandians ready one of the shock tubes at Thunder Range for a blast test.

of the nation's largest urban-industrial centers. The Nixon administration modified this system in 1969, renaming it the Safeguard system. Rather than defending all large cities, Safeguard was intended to protect only the seat of government and Minuteman and Titan missile sites against preemptive surprise attacks.

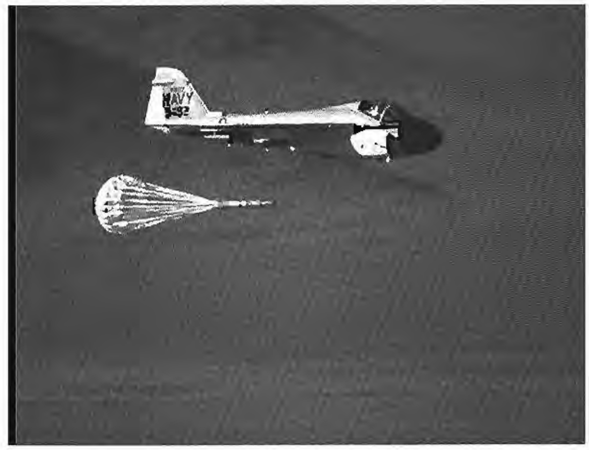
Both the Sentinel and Safeguard systems relied on the Sprint and Spartan antiballistic missiles. With phased-array radars capable of detecting incoming targets thousands of miles away, the larger Spartan missile could intercept and destroy them before they reentered the atmosphere. To protect radar and missile silos against missiles that eluded the Spartans, the quick-reaction Sprint missile could hit them during atmosphere reentry.

Phase 3 development for the W66/Sprint missile warhead began in 1968. Milt Madsen managed Sandia's share. This included design of the warhead firing set, inertial switch, self-destruct device, mounting hardware, and lightning arrestor connectors. Design of the W71 for the larger Spartan missile by a Sandia/Lawrence Livermore team began the same year, and Gunner Scholer, Glen Otey, and Ray Sheppard managed that project with a staff including Don Bohrer, Gary Beeler, and other engineers.

The functional life of the Safeguard system proved brief. The 1972 Antiballistic Missile treaty with the Soviet Union limited the Safeguard deployment to a single site. Then, shortly after it was deployed, Congress terminated its operational funding.

LOW-ALTITUDE DELIVERY

In 1964, the Defense department defined a need to determine the ability of aircraft to invade enemy airspace and evade radar detection, together with evaluations of U.S. radar and antiaircraft defenses. The former resulted from the new Soviet missile capability to down high-flying strategic bombers, as demonstrated by the intercept of Gary Powers' U-2 aircraft. The newly



A Navy A-6 completes a low-level test drop at Tonopah Test Range.

Sandians load an instrumentation pod for low-level testing on an A-4C in 1967.

Low-level flight testing for Joint Task Force Two began in 1965 at Sandia's Tonopah Test Range.

Applications of Sandia's electrooptic ceramics included these flash goggles to protect the eyes of pilots during a nuclear detonation.

developed delta-wing B-58 Hustler high-altitude strategic bomber had its service life severely truncated for this reason. The Joint Chiefs of Staff organized Joint Task Force Two (JTF-2), commanded initially by General George Brown. The task force sought to obtain quantitative information on low-level flight performance for use in future war games, simulator development, and policy decisions on aircraft and weapons procurement. The tests could also furnish excellent training for aircraft pilots and crews bound for Vietnam, where their safety depended on evading Soviet-made surface-to-air missiles.

In late 1964 Don Cotter led a systems study that explored the match between JTF-2's needs and Sandia's technical capabilities. Because Sandia had the knowledge, experience, and hardware immediately available, General Brown requested its assistance. With AEC approval, Sandia agreed to provide the testing instrumentation needed to assess the performance of Air Force, Army, Navy, and Marine aircraft and crews, in addition to the systems needed to collect and analyze the data. Don Shuster headed the Sandia effort centered in John Eckhart's systems evaluation group. Tom Sellers supervised development of instrumentation pods and monitoring equipment; Jim DeMontmollin managed test

For Joint Task Force Two in 1966, Sandia built a flight simulator by projecting film of test flights on a 160-degree screen. From the mock cockpit in the center, pilots reacted to situations presented on the screen.

planning; and John Miller handled site engineering and maintenance.

Less than three months after accepting this mission, Sandia's team had fielded the instrumentation pods to be carried by the test aircraft, the tracking and data collection equipment for aircraft monitoring the telemetry, and the computer programs for data reduction and analysis. By May 1965, low-level sorties had begun at the Tonopah Test Range. "We were trying to duplicate the Vietnam war in real time," recalled Orville Howard of the low-level flight test program, "and trying to understand from a scientific standpoint what was going on and how you could deal with certain problems."

Ray Brin and the Tonopah range crew laid out a zigzag course for the aircraft to follow over terrain ranging from flat to mountainous, marking it plainly with orange barrels. By July, crews of eight different aircraft types from all the services had flown 450 sorties, some flying so low that they clipped the barrels. Using 70-millimeter film, Sandia built a flight simulator for pilot training, projecting film taken during test flights onto a 160-degree screen. Pilots trained in a mock cockpit in the middle of the screen, with their reactions to changing terrain recorded for evaluation.

Each aircraft flying the course carried an instrument pod that transmitted signals for tracking. Aircraft overhead and ground equipment received the signals, and the recorded data went into computers to create a complete profile of each test run. At the end of each day, these reports were sent to the task force headquarters at Sandia. "Interestingly enough," Glenn Fowler later commented, "we found that success depended less on which delivery system was used than on the training and skill of the delivery crew."

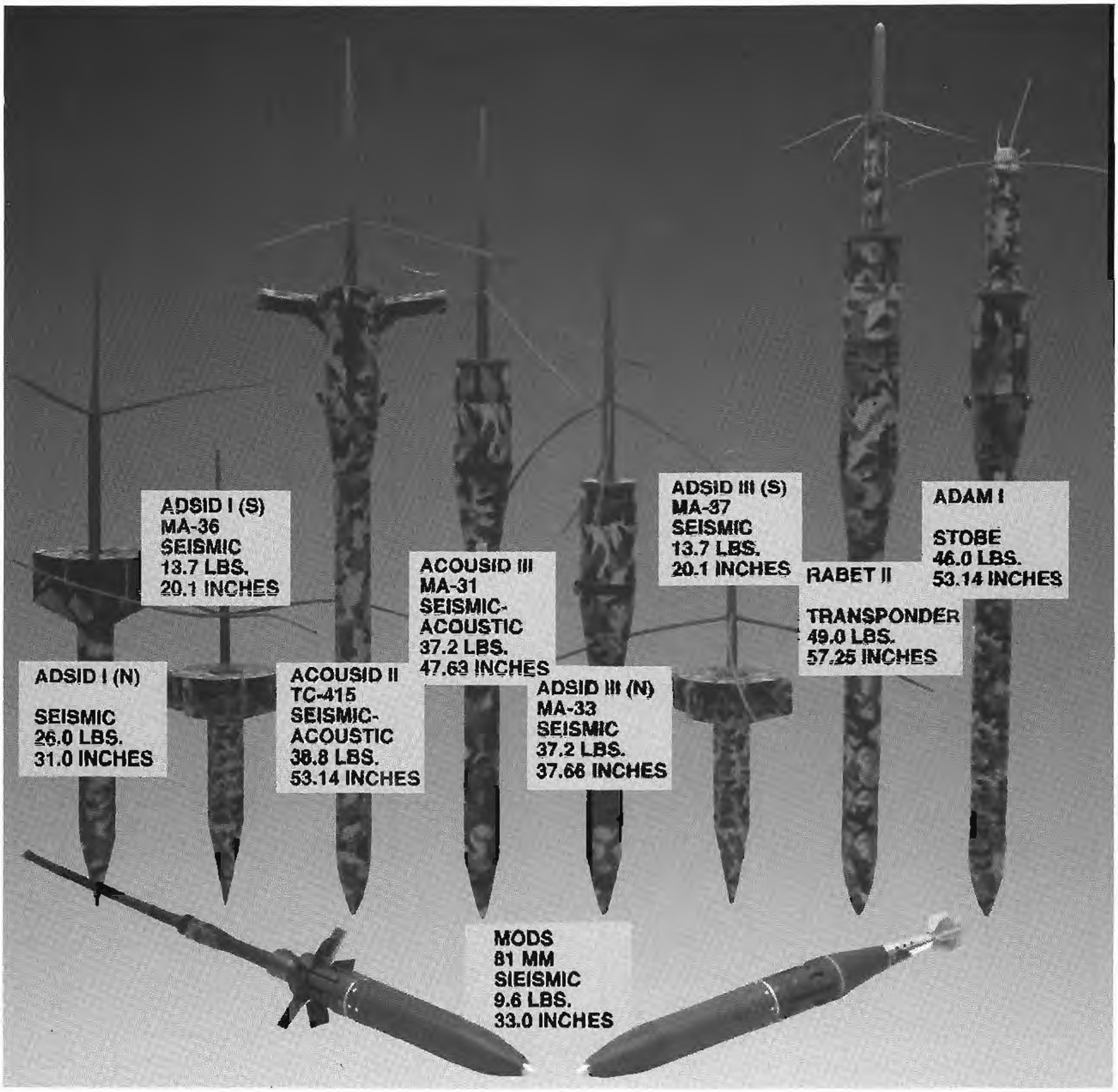
Sandia's subsequent development and fielding of mobile instrumentation freed the low-level test program from the test ranges, allowing more realistic testing over varied terrains. The tests moved in 1966 to rugged terrain in the Ozarks. In 1967 and 1968, hundreds of test flights continued over Arkansas, Louisiana, California, and Oklahoma, with Sandians maintaining and operating the instrumentation. The original task force plans called for continuing testing into the 1970s, but Vietnam provided a more realistic testing ground.

SUPPORT FOR VIETNAM

As early as 1962, Air Force scientific advisors told Monk Schwartz that, in addition to nuclear weapon engineering, Sandia should be prepared to initiate research on the tools needed in limited wars such as that beginning in Vietnam. Schwartz received no specific requests for assistance, however, before President Johnson committed ground troops to Vietnam in 1965. In that same year, Sandia received its first assignments for technological support of the troops in Vietnam.

When testing a prototype of Sandia's unmanned seismic observatory for detecting underground nuclear detonations, Pat Patterson found that it also registered the vibrations from passing trucks and even the footsteps of a passerby, an annoying clutter interfering with seismic analysis. But when Richard Sproull of ARPA visited Sandia to check on the progress of the unmanned seismic observatory and, in passing, described some of the problems faced by the military services in Vietnam, Patterson and his colleagues recognized that the seismic annoyances might be used to detect the passage of convoys or troops along the Ho Chi Minh Trail and they obtained seed money from Sproull in 1965 for expanded research on seismic sensors. "Now it was necessary," said Patterson, "to define more subtle seismic waves, ranging, perhaps, from those caused by an elephant stamping through the underbrush to a coconut falling off a tree in a high wind."

When General Starbird became commander of the Defense Communications Planning Group charged with producing innovative technology for use in Southeast Asia in 1966, he called on Sandia for assistance. Tom Sellers, Tom McConnell, and other Sandians transferred to Washington to



Sandia developed a large family of terradynamic, air-dropped sensors for use in Vietnam.

assist with Starbird's programs. "Starbird was very insistent on our involvement," McConnell noted, "and we had major responsibilities for sensor design."

Starbird's major assignment involved creating an electronic fence between North and South Vietnam to reveal the passage of supply convoys and reinforcements to the south. Because Robert McNamara had announced this program in 1966, it became known as "McNamara's Wall." Although initial plans considered using acoustic buoys developed for submarine detection, Starbird told Glenn Fowler, "I really need something I can drop out of aircraft that will detect people."

Defense contractors in 1966 already had seismic sensors under development, but these had to be planted by hand and connected by wire to earphones at listening posts. Starbird wanted sensors that could be dropped from aircraft and that could transmit by radio their detection of passing troops and vehicles. Moreover, he wanted these deployed to Vietnam within a year.

Ed Villella holds an earth penetrator of the type deployed in Vietnam and points to a terradynamics testing device.

A combination of laboratory capabilities made it possible for Sandia to meet Starbird's goals, as Patterson explained. "Terradynamics is one. The ability to stick something in the ground and predict what kind of shock it's going to encounter and predict how deep it's going to go. The ability to make electronic circuits withstand that shock was there. Knowing about aerodynamics and having our own wind tunnels so we could say right away that it's going to be stable and it's going to separate from airplanes and fly in a predictable manner — all of those things. It was a combination of abilities in past developments that combined to make the first intrusion detector a very satisfactory thing."

Sandia's experience with weapons and VELA program designs made possible quick development of the air-deliverable seismic intrusion detector (ADSID). Bill Caudle coordinated the terradynamic and aerodynamic design (including flight tests) of the family of sensors used in Vietnam. Dropped from aircraft, these penetrated the ground like Sandia's earth-penetrating bombs. Inside these small penetrators were miniature seismometers, and trailing behind were antennas camouflaged to resemble plants. At impact with the ground, rolamites activated the sensors and radio transmitters that then relayed seismic data to receivers in aircraft overhead or elsewhere. Harvey Hawk, Gordon Hawley, John Portlock, and James Scheibner later patented the basic seismic sensor system.

Sandia designed additional sensors and tested them in varied terrain including the triple-canopy jungles of Panama. Portlock and Richard Gossett took prototypes to Thailand for testing along trails like those in Vietnam, while Lyle Wetherholt and Tom Banks demonstrated prototype sensors in Vietnam to the First Cavalry and other combat units.

When sensor designs were completed, Starbird urged Sandia to arrange swift production and deployment, promising that he would provide production funding within a few months. "We went ahead and started working," Fowler said, "because we had confidence in him." Although Schwartz strongly supported this production in advance of formal funding, an AEC review board questioned it. Leonard Jacobvitz, long-time counsel for the AEC Albuquerque office, told the board he had heard the son of an AEC official credit his survival in combat to warnings from the sensors, and he pointed out that they might save more servicemen's lives. "Don't be a jerk, approve it," he admonished the board, "how many lives is it worth?"

Bob Hepplewhite headed Sandia's production task force that managed prototype production, contracted for industrial production, and arranged deliveries to Vietnam. More than 36,000 ADSIDs and smaller numbers of other models went to Vietnam.

Although McNamara's Wall was never completed, Sandia's sensors passed the combat test at the siege of Khe Sanh in 1968. General William Westmoreland ordered the Seventh Air Force, commanded by General George Brown, who earlier had headed Joint

Task Force Two at Sandia, to seed the approaches to Khe Sanh with seismic and acoustic sensors. After the siege was broken, the Marine commander of the bastion estimated that warnings from the sensors of imminent attacks had reduced casualties among the defenders by as much as fifty percent, while allowing them to inflict greater damage on the assaulting forces. Many other forward fire bases soon had Sandia's sensors planted around their perimeters.

Sandia continued improving its sensors and in 1969 turned its attention to the development of an operational Battlefield Area Surveillance System (BASS). This system furnished sensor data to field commanders, who could detonate land mines planted near the sensors to destroy targets without waiting for air strikes. For their protection, friendly troops carried LORAN (long-range aid to navigation) monitors relaying their positions at all times to the field commanders.

Although Sandia's production of seismic sensors for Vietnam ended in 1971, use of improved versions of the sensors continued into the 1990s. The Army deployed such sensors in Korea and Europe. Sellers, Dusty Cravens, and other Sandians also worked with the Border Patrol to develop miniature BASS systems to monitor intrusions at critical border sectors. During the 1980s, the Marine Corps funded Sandia's development of improved sensors tailored to monitor activities at amphibious landing sites, a task managed by McConnell and a Sandia team. This program later led to the tactical remote sensor system and miniature intrusion detection system (MIDS), as well as sensor programs that use acoustics and video to identify vehicles for intelligence applications. Because of their extremely low cost, MIDS sensors have become very popular with various civilian law enforcement agencies as well as the military. Patterson described the sensors for Vietnam as "one of Sandia's first advanced military concepts outside the nuclear weapons area and a forerunner of much of the sensor technology that continues at Sandia even today."

Among other efforts by Sandia in support of the troops in Vietnam were new types of conventional weapons. In December 1968, the Air Force asked Sandia to develop a fuel-air explosive bomb that could be delivered by A-1 aircraft and later F-4 aircraft. Sandia organizations managed by Max Newsom and Bill Hoagland responded with the design and testing of two fuel-air bomb designs code-named Pave Pat and Garlic.

While conventional explosives chemically integrate the explosive and oxidizing components, fuel-air explosives carry fuel, perhaps propane or butane, as a pressurized liquid and use the oxygen in the atmosphere

During the 1960s, Sandia developed fuel-air explosives such as this Pave Pat bomb for use against blast-sensitive targets.

as an oxidizer. As a rule of thumb, 1,000 pounds of fuel can create a lethal overpressure equivalent to 10,000 pounds of TNT, sufficient to destroy people and materials even if they are hidden in underground tunnels.

An explosive cutter in the Pave Pat bomb split it open at impact, releasing the fuel to mix with air and form an explosive cloud, which a small explosive trigger detonated. The major design challenge involved delaying trigger detonation until the cloud had expanded sufficiently to mix with the air. If ignited prematurely, the cloud burned with little or no blast overpressures. When Sandia air-dropped early Pave Pat prototypes at Tonopah Test Range, for example, they burned rather than exploded due to improper cloud formation and mixing. To create a controlled test environment, Dave Bickel and Sandia's testing team in 1968 stretched cables between two peaks in the Manzano hills. Rockets were added to pull prototypes of a smaller, free-fall version named Garlic down the cables at the velocities required for realistic testing. Using an ingenious technique employed previously by other military branches, the test crew placed empty beverage cans around the drop area. If the bomb created a blast, it crushed the cans; if it only burned, the cans remained intact. Testing of the smaller, free-fall version named Garlic achieved descent velocities of 800 feet per second before Sandia delivered the device to the Air Force for further development.

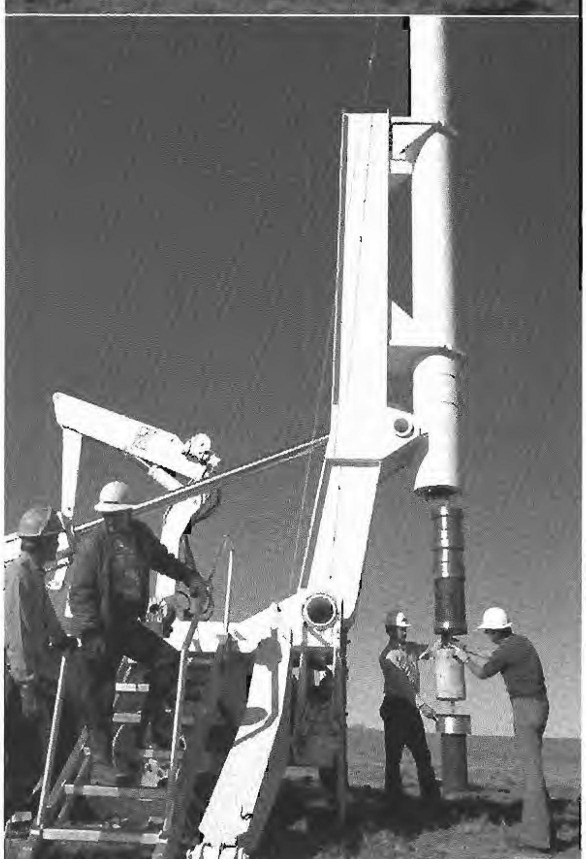
The first prototypes of Pave Pat were sent to Vietnam in 1968 accompanied by Hoagland, Richard Beasley, John Weber, and Rex Steele as technical representatives to orient servicemen in their use. In 1971 Beasley and Paul Langdon, among other Sandians, made the trip with the second group of Pave Pats. Later that year, Beasley and Langdon received shrapnel injuries, and, since these were not critical, the two were returned to Albuquerque in time for Christmas.

Sandia conducted other interesting exploratory programs during the Vietnam era. Handaxe, as the code name implied, involved designing a weapon that could chop down vegetation to open a helicopter landing zone. In this case, an explosive charge propelled spinning rods at sufficient velocity to clear an area of jungle. Another example, Rumpler, blocked vehicular traffic by firing earth penetrators into roadways where underground detonations could produce craters. Detonation of a demolition explosive near ground surface would produce merely a shallow crater; burial below the surface beforehand could open deep barriers to traffic.

The Rumpler studies entailed a joint effort by Sandia and the Army's Picatinny Arsenal. Max Newsom, Wayne Young, Larry Seamons, and other Sandians employed a Davis gun — a large recoilless rifle open at both muzzle and breech — for firing earth-penetrator weapons into various soils and rock formations. By sandwiching propellant between the penetrator and a reaction mass, the Davis gun could fire projectiles weighing up to 400 pounds at up to 3,000 feet per second (compared to only 1,400 feet per second for aircraft drops), providing the high velocities needed to duplicate the impacts and penetrations of supersonic weapons into geologic media.

To use both the Davis gun and aircraft drops for terradynamics studies, Sandia opened a temporary test range twenty miles east of Albuquerque at Edgewood in 1968. In the spacious Estancia valley, Sandia leased range land, installed utility lines and an airstrip, and added an irrigation system to saturate the soils into rice-paddy-like consistencies. Most test drops at Edgewood came from an old observation aircraft modified by Sandia with bomb-release racks and electronics as a substitute for more expensive military aircraft and helicopters. Sandia's use of the Edgewood range for terradynamics research continued for a decade.

Another conventional weapons program involved the development of the Murine radar, so named because it was tested on a Redeye missile. Field experience indicated that the Soviet-made, heat-seeking, surface-to-air missiles used by North Vietnam could bring down helicopters and small aircraft. Studies also showed that high-intensity flares could decoy the infrared-guided missiles away from the helicopters, if early detection



of the approaching missiles were possible. In 1970, Charles Blaine led a Sandia team conducting research on Murine, a missile-warning radar that could detect incoming missiles and deploy the flares as decoys. After a competition in 1971, the Army selected Sandia's design for development.

The Murine design presented two major technical challenges: distinguishing missiles from ground clutter and preventing false alarms from helicopter rotor blades, which had a velocity similar to approaching missiles. Jack Webb and Roger Gray invented a discrimination circuit that picked missiles out from background clutter on the basis of their velocity. Because helicopter rotor blades created repetitive, short signals, the Webb and Gray discriminator circuit reacted only to signals longer and steadier than those of the rotor blades. Sandia transferred this technology to a defense contractor for production, and the system entered service during the 1980s.

In addition to Vietnam, other international events influenced Sandia's exploratory programs. During the 1967 Six-Day War in the Middle East, Egyptian forces sank an Israeli ship with a guided missile. This revived interest in guidance and control systems for missiles in the United States and elsewhere. In addition, the 1973 Yom Kippur War in the Middle East reinforced assessments of the value of defensive electronics, of electronic countermeasures, and of guided or "smart" bombs — another aspect of the electronic battlefield.

At Sandia, Newsom, Sellers, Tom Edrington, Don Rigali, and others focused attention on the engineering of precision delivery systems and on applications of sensors and data collection technologies to

Top: A recoilless Davis gun, designed at Sandia, fires an earth penetrator into the ground near Edgewood, New Mexico in 1974. Davis guns have barrels open at both breech and muzzle. At Sandia, they were used for analysis of the passage of projectiles through soils.

Bottom: Sandia's field test group at the Edgewood test range loads a Davis gun for testing earth penetrators. The two specialists at right are centering the propellant between the projectile and the reaction mass.

Max Newsom and Tom Anderson check a tester for weapon firing systems.

intelligence analysis, to national safeguards and security programs, and to instrumentation for the energy programs of the 1970s. In time, the confidence in Sandia's capabilities acquired by the armed services brought it reimbursable non-nuclear weapons projects including antiarmor warheads, battlefield robotics, propellants, explosives, fuzing components, and guidance and control systems.

Sandia's expertise also brought it assignments from the U.S. intelligence community. During the early 1960s, intelligence agencies occasionally requested Sandia's technical assistance, and in 1966 this became a continuing relationship. Legend says that AEC Commissioner James Ramey, while enjoying a game of golf with intelligence officials, offered them the technical assistance of the AEC laboratories. Leon Smith, Andy Lieber, Jack Howard, and Howard Stump negotiated agreements on Sandia's behalf, explaining that Sandia's background in telemetry, aerodynamics, arming and fuzing, and general engineering technology could serve several intelligence needs. A major interest of the 1960s, for example, involved examining data collected through indirect means from foreign nuclear or reentry vehicle tests to hypothesize the designs and capabilities of the weapons. Offering a classified environment for research, Sandia had the expertise required for identifying weapons components and characteristics. Its traditional emphasis on rugged and reliable engineering applied to equipment for remote intelligence acquisition as well as nuclear weapons.

Andy Lieber initially managed Sandia's systems research for intelligence agencies during the 1960s, forming an organization including several dozen Sandians. According to Roger Hagengruber, Sandia's intelligence program suffered budget cuts during the retrenchments of the early 1970s, but later in the decade Bob Clem secured funding to revive the program and by the 1980s Sandia's research had diversified sponsors among the intelligence community. Perhaps Sandia's foremost contributions emanated from its assumed role as a "red team," analyzing U.S. weapons technology from foreign perspectives to detect weaknesses.

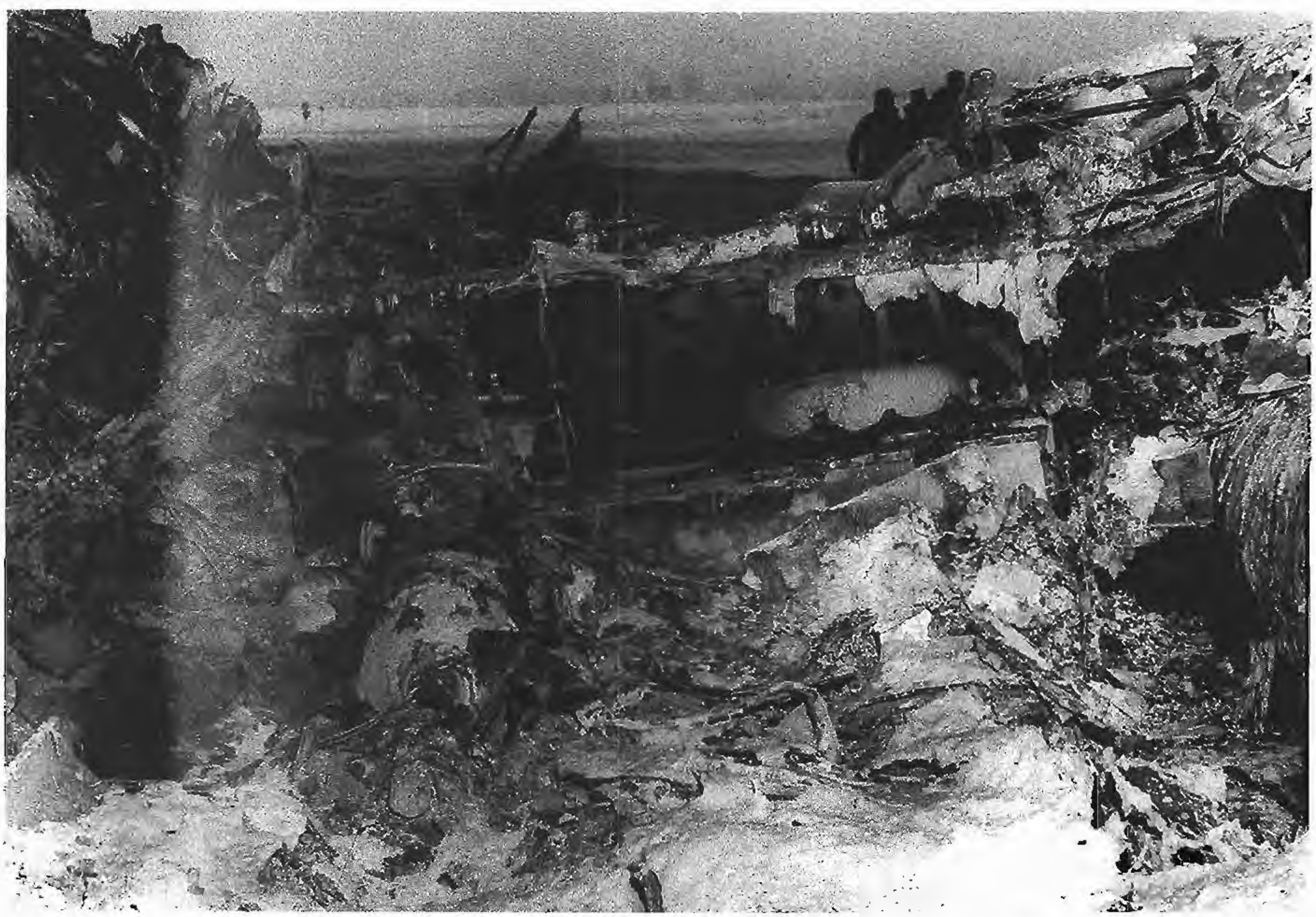
In 1968, John S. Foster, Jr., Director, Defense Research and Engineering (DDR&E), awards the Secretary of Defense Meritorious Civilian Service Medal to Don Cotter for his service as Special Assistant to Deputy Director, DDR&E (Southeast Asia Matters). Cotter held this post while on leave-of-absence from Sandia from 1966 to 1968. Observing the ceremony are the Cotter children, Elaine, Jeff, and Doug (who later came to work at Sandia), and Mrs. Cotter.

SAFETY OF NUCLEAR WEAPONS

When the Strategic Air Command went on quick reaction alert in 1958, with nuclear-armed aircraft constantly in the air and on standby, the chances for aircraft accidents with nuclear bombs aboard multiplied. When accidents occurred during the 1960s, they had far-reaching effects on Sandia's approaches to nuclear weapon safety design.

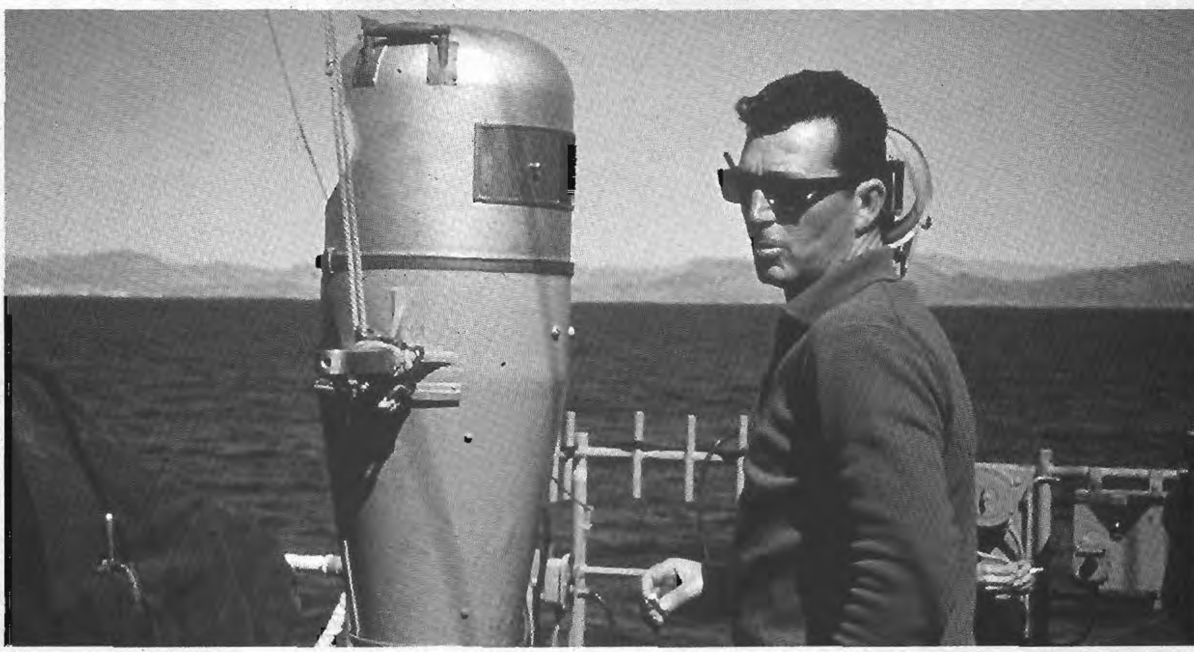
A 1964 nuclear weapon incident at Bunker Hill Air Force Base in Indiana provided an early indication of the need for a more extensive abnormal environment testing program at Sandia. When a B-58 Hustler slid off a runway in winter, a B43 bomb under its wing landed in a snow bank. The plane's wing crushed down on the bomb and the plane caught fire, heating the upper bomb casing. This was a unique and previously unevaluated situation since no one had ever considered that a bomb might experience extreme cold, crushing impact, and intense heat simultaneously.

Among other aircraft mishaps, accidents over Spain and Greenland in 1966 and 1968 garnered international attention. The tragic collision of a B-52 aircraft and refueling tanker over Palomares, Spain, in 1966, killed all but four crew members and released four nuclear bombs to plummet more than five miles to earth. Although the high explosives of two bombs detonated when they struck, there was no nuclear yield. Because parachutes partially deployed on the other two, one landed safely aground and the other drifted out to sea. To help the Navy recover the bomb from the sea, Stuart Asselin, Randy



A B43 is half buried in the frozen earth and half exposed to fire in the crash of a B-58 Hustler at Bunker Hill. After the fire, the plane's wing fell and crushed the bomb. *Left of the photograph center,* the weapon nose is exposed.

RECOVERING THE LOST H-BOMB



The fisherman, Francisco Simo y Orts, helped the Navy locate the sunken bomb.

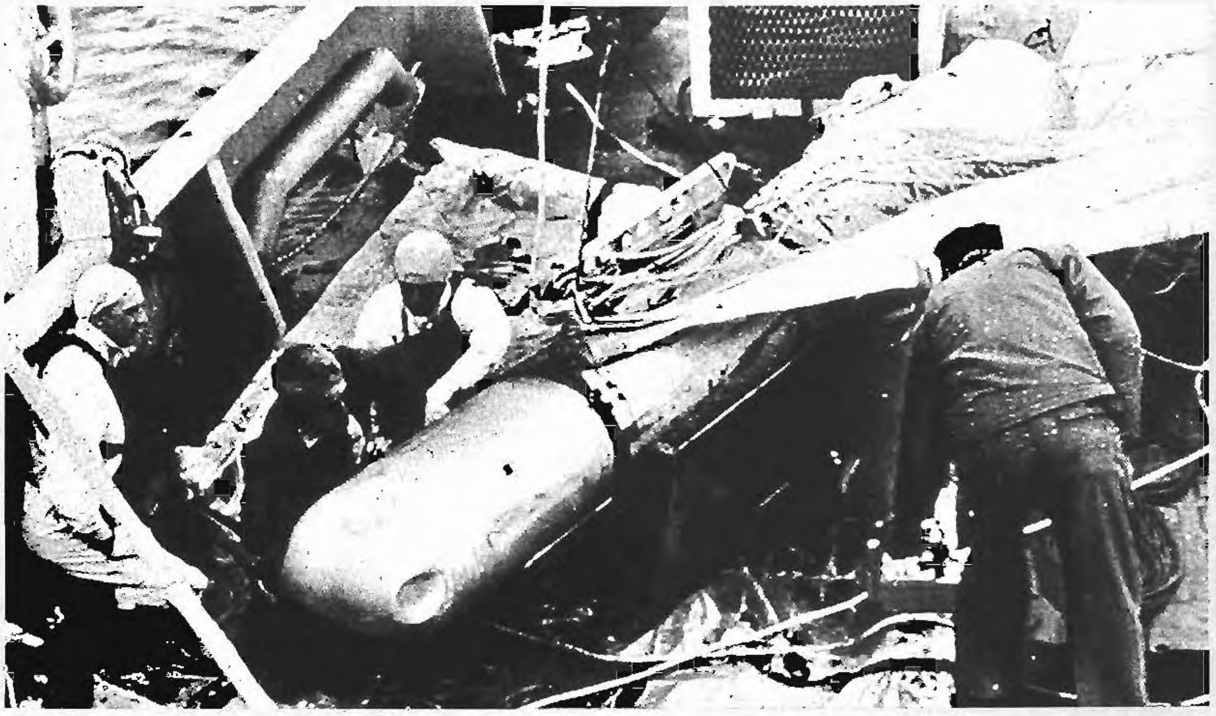
Palomares

On January 22, 1966, a B-52 carrying four thermonuclear B28 bombs collided with a KC-135 refueling tanker above Palomares, Spain, on the Mediterranean Coast. The accident occurred at 30,500 feet altitude about two miles inland, with the wind blowing out to sea. The tanker's crew and three of the B-52's crew were killed, but four of the B-52 crew parachuted to safety.

The B28s, equipped with both 16-foot diameter and 64-foot diameter parachutes, were torn from the bomb rack when the B-52 broke up. Three bombs landed on the shore. The 16-foot parachute deployed on the first bomb, and it struck the ground with minimal damage. The second bomb tumbled free fall, impacting at about 325 feet per second, causing its high explosive to detonate and scatter plutonium. The third bomb's damaged 16-foot parachute deployed, but it hit the ground at about 225 feet per second, also exploding and scattering plutonium over several hundred acres.

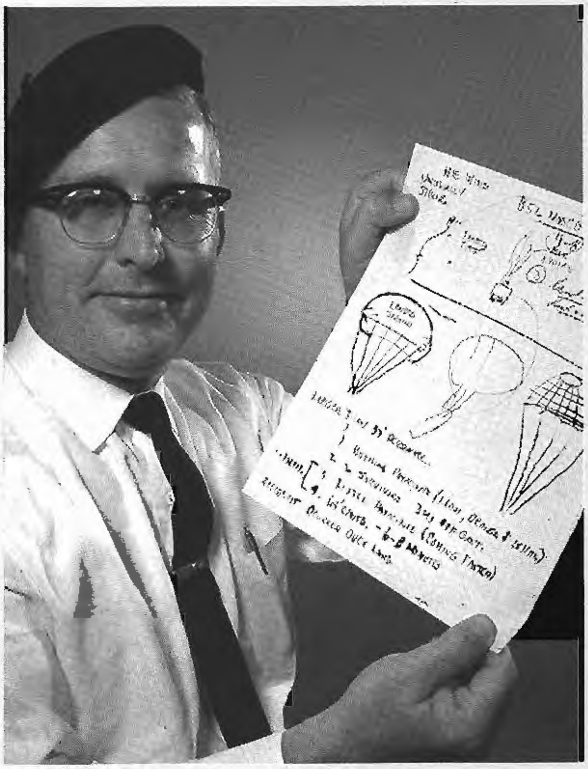
Within hours the U.S. Air Force had located the three B28s on the shore. However, after days of searching, the fourth bomb could not be located. General Delmar Wilson, commanding the 16th Air Force, formed a team from Sandia and the Air Force to conduct trajectory calculations at Palomares and to predict the bomb's location. Uncertainty about the winds and whether or when the 64-foot parachute had deployed resulted in a large sea area to search. Francisco Simo y Orts, who was fishing five miles offshore at the time of the accident, said he saw a "dead man" attached to a parachute, which took 6 to 8 minutes to descend before hitting the water about 75 yards seaward of his boat. Randy Maydew sketched the 64-foot general-purpose parachute and the 16-foot ribbon parachute, and Orts sketched the parachute and dead man he had seen near his boat. This convinced Maydew that Orts had seen the fourth bomb go into the sea with its 64-foot parachute attached.

The team briefed General Wilson and Admiral William Guest, commanding the Navy task force for the recovery, and recommended the search be centered where the fisherman had seen the bomb. On March 15, the small submarine *Alvin* located the



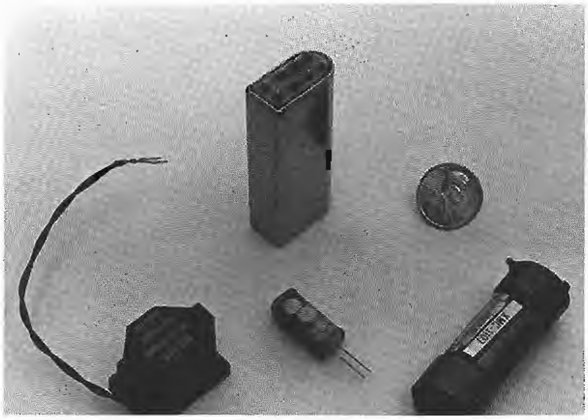
The last bomb was hoisted onto the Navy ship Petrel's deck on April 7, 1966, 80 days after the accident. Sandian Stuart Asselin was on-board at the time.

bomb near that site at a depth of 2,250 feet. Attempts to attach lines to the parachute resulted in the bomb sliding down a steep underground slope. *Alvin* relocated the bomb, but a nylon tow line failed when a second recovery was attempted on March 24. The cable-controlled underwater vehicle, CURV, finally brought the bomb up to the deck of the USS *Petrel* on April 7. The recovered bomb casing is now displayed at the National Atomic Museum in Albuquerque.



Randy Maydew in 1966 displays sketches used by Spanish fisherman Francisco Simo y Orts to describe the parachutes he saw from his boat. Maydew's black beret was high fash

The recovery required eighty days and cost more than $50 million. The 4,000 participating servicemen and civilians determined the limits of plutonium scattering from alpha radiation measurements, plowed up 386 acres of fields, shipped the contaminated soil to an AEC site in South Carolina, and settled damage claims. That the crash did not result in a nuclear detonation was reassuring, but costs of the accident were high. International repercussions followed, and overflying Spain with nuclear bombs ceased at Spanish request. The accident had one positive outcome: major improvements in safety designs for the U.S. nuclear stockpile followed as a result of lessons learned during this accident and other mishaps.



Sandia achieved remarkable miniaturization of weapon components. Back next to the penny is a thermal battery, and in the foreground from left to right are an impact fuze, a rolamite switch, and an inertial switch used as an environmental sensing device.

Maydew, Bill Barton, Sam Moore, Bill Hoagland, and Bob Reed went to Palomares, analyzed the bomb's trajectory and related factors, and provided the Navy with a predicted location. Using this prediction, the Navy found the bomb underwater and eventually recovered it, although not until an international furor ensued to protest the flights over Spain.

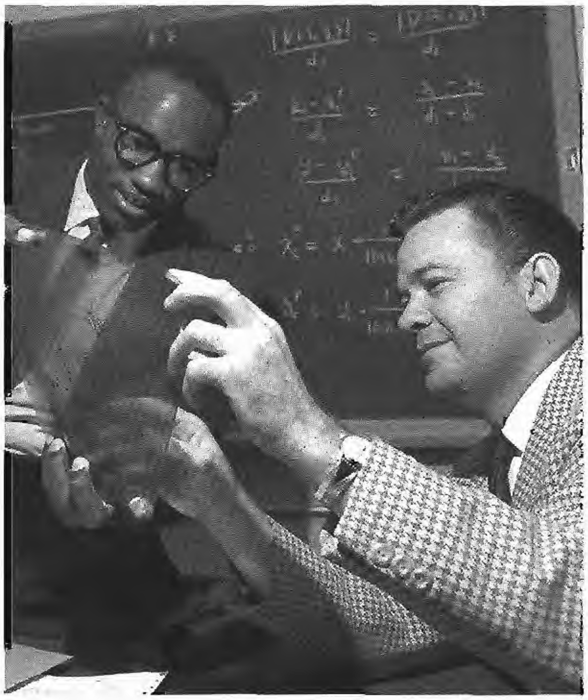
In 1968, a B-52 caught fire over Greenland, the crew bailed out, and the plane crashed on the ice near Thule. Although high explosives in the four bombs detonated, the nuclear packages did not. Again, Sandians went to the accident site to assist the Air Force Team with the search and monitor the removal of ice contaminated by the accident. Perry Lovell and Ron Hoffman of Sandia California's environmental health division provided environmental monitoring, while Roy Lambert and Jack Hickman served as members of a response team involved in search and recovery operations.

These and other incidents fostered closer scrutiny of nuclear weapon safety at both the DoD and the AEC. In 1968, Carl Walske, chairman of the Military Liaison Committee, promulgated a set of quantitative design safety criteria whose objective was to define specific numerical goals for the likelihood of an unintentional nuclear detonation. In particular, Walske specified that measures must be taken to insure that the probability of detonation of a nuclear weapon in a fire, impact, or other abnormal environment should not exceed one in one million per accident and that the probability of detonation of a nuclear weapon in normal environments such as storage and transportation should not exceed one in one billion per weapon lifetime. In addition, the new standards mandated that "In the event of a detonation initiated at one point in the high explosive system, the probability of achieving a nuclear yield greater than four pounds TNT equivalent shall not exceed one in one million." These quantitative criteria, combined with the earlier DoD qualitative standards of 1960, have worked to assure that nuclear weapons would not have a significant nuclear yield in accidents or when jettisoned from aircraft.

Responding to these intensified safety concerns, Sandia sought to design an "accident-proof" bomb for Air Force use during quick-reaction alerts. Max Newsom managed this effort, called Project Crescent, at Albuquerque and Tom Brumleve, Arlyn Blackwell, and Don Gregson participated at Livermore.

Sandia had continuously participated in nuclear weapon system safety reviews for the DoD and AEC since the late 1950s; however, Jack Howard decided to concentrate attention on design safety, independent of the pressures accompanying project schedules, by establishing an independent safety group at Sandia in 1969. The new department, created by Bill Stevens, included the existing systems safety review division supervised by Parker Jones and a new safety division under Stan Spray. In 1974, a safety assessment technology division, initially managed by Jack Hickman and later by Dick Smith, was added to develop techniques such as risk and fault tree analysis for evaluating evolving safety concepts.

One major outcome from Stan Spray's group was the development of a novel nuclear detonation safety concept. In this concept a "strong link" in conjunction with an exclusion region barrier isolated a weapon's detonators and firing sets from electrical signals. Only when activated by unique signals would the "strong link" allow



In 1963, mathematicians Craig Jones and Harvey Ivy participated in Sandia's studies for NASA of high-altitude winds and devised a method for using photographs to determine wind data.

firing signals to pass through the exclusion barrier to the firing set and detonators.

Also incorporated was a "weak link," in which components vital to arming a weapon were deliberately designed to fail during accidents and fires before the strong links were destroyed. "The beauty of this simplifying concept," Leon Smith observed, "is that it gives us an appropriate balance between operational readiness and safety."

By 1972, the aggressive and independent design safety effort, which included evaluation of a number of novel safety designs, allowed Sandia to develop systems that met the stringent Walske criteria. In 1977 the fifth modification to the reliable B61 bomb was fielded. It was the first weapon to incorporate the weak-link/strong-link/exclusion-region/unique-firing-signal design, a concept that would come to be called enhanced nuclear detonation safety (ENDS). Sandia applied these improvements as appropriate to its designs and during the 1970s initiated a stockpile improvement program led by Dick Brodie, seeking to install enhanced nuclear safety components in older weapons. These efforts continued until the Cold War ended and the dismantlement of older weapons began.

RESEARCH AND EXPLORATORY SYSTEMS INITIATIVES

In response to the 1963 LTBT safeguard requiring maintenance of vigorous weapons design laboratories, Monk Schwartz and his colleagues had sought to diversify Sandia's efforts into programs outside its traditional nuclear weapons responsibilities. They achieved notable success. By 1966, the JTF-2, Vietnam support, VELA, space power safety, and related missions supplied nearly fifteen percent of Sandia's total budget, opening challenging new fields to Sandia's technical staff.

When Schwartz was about to retire in October 1966, his staff asked his thoughts on Sandia's future. He replied that it always irritated him when Sandians questioned him on this subject. "The future of Sandia is not going to be determined at the management level," he asserted, "it's going to depend on you and the rest of the people like you. If you can come up with enough sound ideas, management will see to it that they get somewhere."

That autumn, John Hornbeck succeeded Schwartz as president. Like Julius Molnar, Hornbeck had earned degrees from Oberlin College and the Massachusetts Institute of Technology, and, like Molnar, he had joined the Bell Laboratories' team that launched the age of semiconductors and microelectronics. When AT&T created the subsidiary Bellcomm company in 1962 to provide systems engineering for the NASA Apollo program, Hornbeck became Bellcomm's president, leaving that position in 1966 to join Sandia. He once remarked that "bright people tend to be brash," and most associates thought he fit that model, always moving, often brusque, and with a definite flair.

John Hornbeck directed systems engineering for the NASA Apollo program before serving as president of Sandia from 1966 to 1972.

In addition to diversification, Hornbeck sought to sustain a vibrant laboratory by enhancing its research capabilities. "We need more technical depth and capability at [Sandia] Livermore to solve our everyday problems," Hornbeck decided, and in 1968 he sent Tom Cook to Livermore with a charter to build an applied research organization.

Gayle Cain, *right*, explains Sandia California's materials impulse testing to Tom Cook, Leo Gutierrez, and General Edward Giller of the AEC.

One important weapon development project at Sandia California during the 1960s focused on tritium, a hydrogen isotope used in neutron generators and gas reservoirs for initiating weapon detonations and boosting yields. In 1960, Lawrence Livermore, in contrast to Los Alamos, had assigned the responsibility for gas reservoir design to Sandia. Because half the tritium decays into a helium isotope in about twelve years, the maintenance of nuclear weapons required regular replenishment of tritium supplies, and Sandia sought ways to use tritium more efficiently and to extend the maintenance cycle. Supporting this research, a tritium laboratory opened at Livermore in 1968. As Cook explained, "The decision was made that it would pay off to put applied research effort into how to handle tritium, to store it, and to inject it into weapons at the proper time."

One of the research payoffs grew out of investigations by Mark Davis and Jim Schirber, who combined the results of helium implantation studies by Walter Bauer and low-temperature tritide studies of Harry Weaver and Bill Camp to explore tritium's effects on metals. Because tritium decays into a larger helium molecule, Davis and Schirber predicted the larger atom would cause embrittlement and subsequent cracking of the metals. Examination of metal vessels in which tritium had been stored proved that the postulated mechanism outlined by Davis and Schirber existed, and Sandia began intense research to identify alloys that could resist embrittlement.

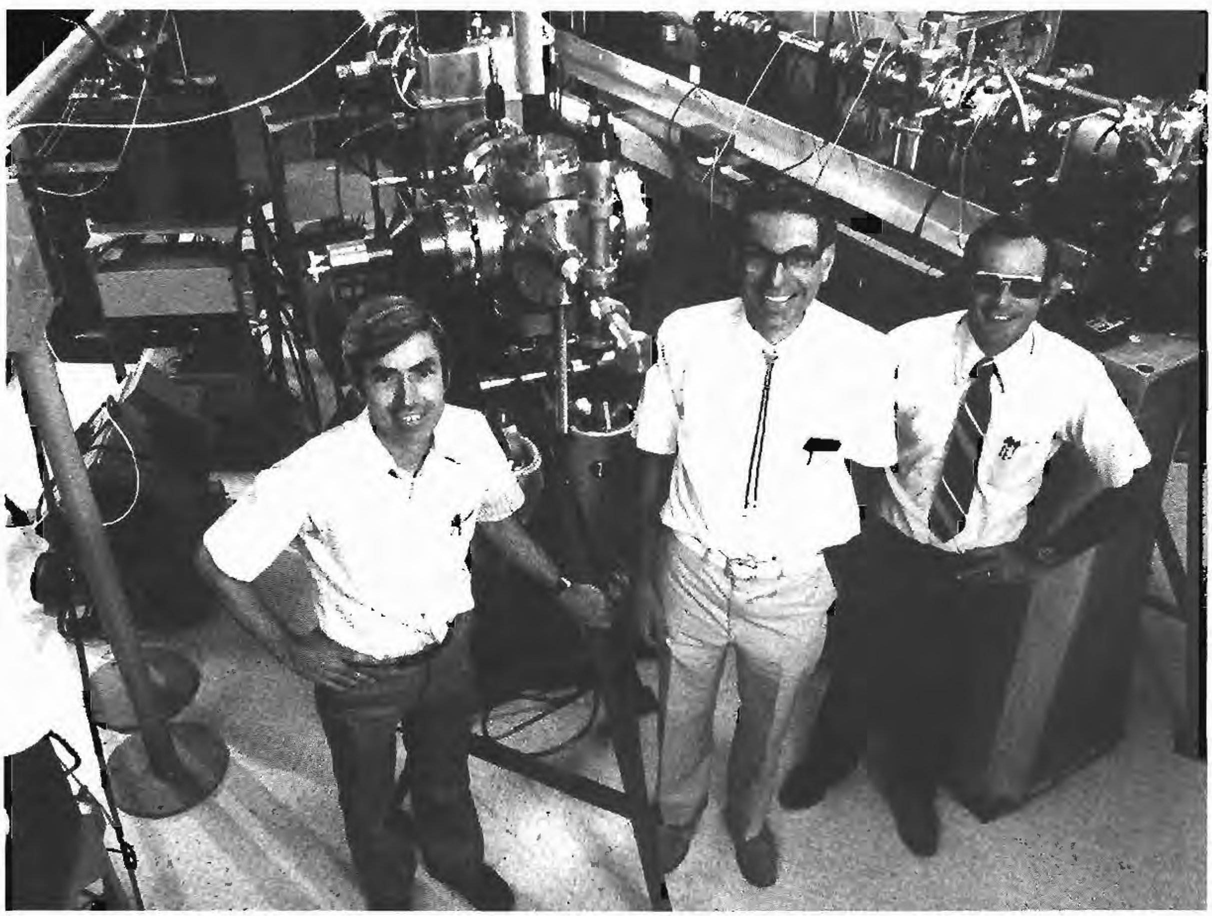
Hornbeck instituted other management initiatives. "We reorganized laboratory functions in 1968 and have set up a new cost control system," he announced. To improve budgetary control, Sandia adopted a budget control system modeled after the system used at Bell Laboratories. This new approach, called the case system, moved budget responsibility from administrative support organizations directly to the line managers who were responsible for the work.

To further bolster research, Sol Buchsbaum became Sandia's vice president for research and Al Narath became director of solid-state sciences. Walt Herrmann, Sam

Thompson, and associates used computer modeling in conjunction with the results of shock wave experiments and field tests of Lynn Barker, Barry Butcher, Darrell Munson, Jim Asay, Lee Davison, Bob Graham, Bill Benedick, Robert Bass, and many others to bring to Sandia a leadership role in shock wave mechanics and physics. Whereas Los Alamos and Lawrence Livermore worked to magnify pressures in their implosion systems, the Sandia emphasis was to mitigate stresses in order to enable system and structural survival. "You can operate much more efficiently and productively," explained Herrmann, "if you don't have to rely exclusively on cut-and-try engineering — bomb drops for example — to find out how systems will behave when subjected to impacts or explosions."

In 1969, Fred Vook, Tom Picraux, Herman Stein, Keith Brower, Jim Borders, and colleagues moved from studies of radiation effects to research on implantation of ions in semiconductors and alloys, and the use of ion beams for precise near-surface analysis of materials such as neutron tube films. For this research, they converted a Van de Graaff accelerator from electron to ion beams, a conversion made possible when Sandia completed a relativistic electron beam accelerator in 1969 to provide fast electron pulses for materials research. Much of this research focused on using ion implantation as a substitute for surface doping of semiconductors.

In addition, the value of a Sandia technique for plating metal alloys with ions caught the attention of AEC chairman Glenn Seaborg. Sandia's research indicated that ion bombardment could clean and plate metals at the same time, providing improved corrosion protection compared with commercial electroplating. Seaborg promoted this process as a significant technology spin-



Tom Picraux, Fred Vook, and Paul Peercy, leaders of ion-implantation and solid state research, stand in front of an ion accelerator.

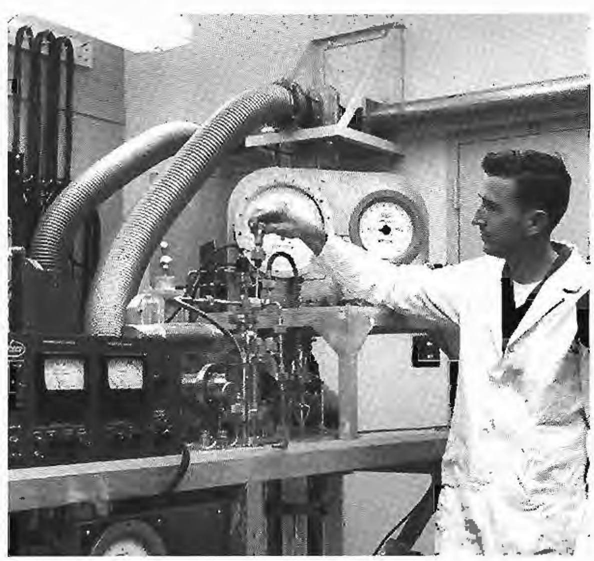
Don Mattox checks the ion-plating apparatus that interested AEC chairman Glenn Seaborg in 1967.

off from AEC-sponsored research. He announced that Sandia's method produced stronger bonds and superior plating of such incompatible combinations as aluminum on steel, or copper on aluminum, and suggested that it might well find many civilian applications.

In 1969, Sandia established a non-destructive testing laboratory, managed initially by Bill Mottern and Bob Baker, to use gamma and x-rays along with ultrasound, infrared, magnetic flux, and other technologies for internal inspection of materials and components without disassembling or destroying them. Doug Ballard and O'Neill Burchett directed the initial non-destructive research program, analyzing the internal parameters of carbon nosetips for reentry vehicles. Frank Neilson and Tom Edrington managed groups that developed non-destructive testing methods useful in studies of weapons and their components as well as energy resources and non-weapon materials.

To concentrate Sandia's resources on research, Hornbeck and his staff essentially ended Sandia's production engineering function. The manufacturing development organization, which had its roots in the 1940s Road department, closed, with its remaining functions transferred to other divisions, and the AEC and Sandia transferred production engineering to contractors. From then until the

Bill Mottern of the Non-Destructive Testing Laboratory used an x-ray of a motorcycle for test demonstrations.



Sandia's director of solid state physics, Al Narath, observes an experiment by David Barham during the late 1960s.

restructuring of the weapon complex in the mid-1990s, Sandia's production role consisted of small lots of items such as ferroelectric ceramics or microelectronics in which new concepts and high reliability demanded close coordination between design and production.

Reflecting the end of its production responsibilities and its advance into the research vanguard, Hornbeck coined the name "Sandia Laboratories" to replace Sandia Corporation as the proper organizational name in December 1969. Schwartz had earlier considered a change to "Laboratory," but had hesitated because all contracts and legal documents bore the name Sandia Corporation. Hornbeck decided to leave the name Sandia Corporation on legal documents as the operating entity, but to change the name by internal fiat to Sandia Laboratories. Sandia's team in California became Sandia Laboratories, Livermore, and the team in New Mexico became Sandia Laboratories, Albuquerque.

SUPER LAB THAT NOBODY KNOWS

When Hornbeck became Sandia's president, it had nine non-weapon programs underway, constituting about fifteen percent of its total budget. These were special or reimbursable programs funded by Defense agencies and NASA, or by AEC offices other than Military Applications. Hornbeck favored continuing these non-weapon programs, provided they used Sandia's special talents, identified by Hornbeck as "sophisticated technology, an ability to react fast, and a willingness to take experimental or untried routes."

By 1970 most of Sandia's special and reimbursable programs were ending. Some ended simply because Sandia completed its work. For example, the planetary quarantine program for NASA, assuring that microorganisms did not hitchhike to or from space aboard lunar and interplanetary spacecraft, closed because Sandia's team had completed the essential research and development.

In 1968, John Hornbeck, Senator Clinton Anderson, Senator Joseph Montoya, and Ray Powell examine a VELA satellite model.

Others ended because Hornbeck objected to micromanagement by the sponsoring agencies; he thought sponsors should specify what they wanted, but not dictate exactly how the research should be performed. In 1970 he ended Sandia's participation in all aspects of the SNAP program except quality assurance. "The AEC Division of Space Nuclear Systems had a view of Sandia's role in the program that was different from ours," Hornbeck explained, concluding, "the difference of opinion led to our decision to ask AEC to handle the whole thing."

Nor did Hornbeck much approve of soliciting new opportunities to replace those ending during the late 1960s. "We prefer not to seek reimbursable work actively," he said, "but rather to have our work sell itself." New customers did not line up at Sandia's door, however, and its reimbursable workload decreased. Outside of the weapon program agencies, Sandia was still, as *Popular Mechanics* reported in 1969, "The Super Lab That Nobody Knows."

In some cases, Sandia's traditional low profile offered advantages. During the anti-war protests on university campuses during the late 1960s, for example, Sandia recruiters Herb Pitts and Jim Schirber escaped the abuse heaped on representatives of other laboratories and defense contractors, largely because Sandia remained a mystery to most students. But low visibility did not attract new customers. When Sandia's development of the integrated warhead reentry body for the Navy's Poseidon missiles was completed in 1970, a hiatus ensued before the Navy requested similar engineering for the Trident fleet ballistic missile. The sole diversified program of any size remaining at Sandia after 1970 was the VELA satellite detection system, neither a special nor a reimbursable program but sponsored by the AEC Division of Military Applications.

"Like every federally funded agency in the country," Hornbeck said in 1970, "we are feeling the effects of the tight money situation." In April 1970, Sandia experienced its first personnel layoff and substantial budget flattening since 1961.

"I was surprised at Nixon and Kissinger, who you would think would be more hawkish, since Henry Kissinger was a consultant to the laboratories," said Sandian Leo Gutierrez, reflecting on the budgetary shortfall, "but we saw the biggest slowdown ever, possibly because of the maturity of the weapons program at that time." Yet the decline in funding was general, affecting not only Sandia but also AEC laboratories engaged in commercial power reactor research, Defense agencies, and NASA as well. Indeed, the decline represented systemic changes in the American economy that reduced funding for research and technology in both the private and public sectors.

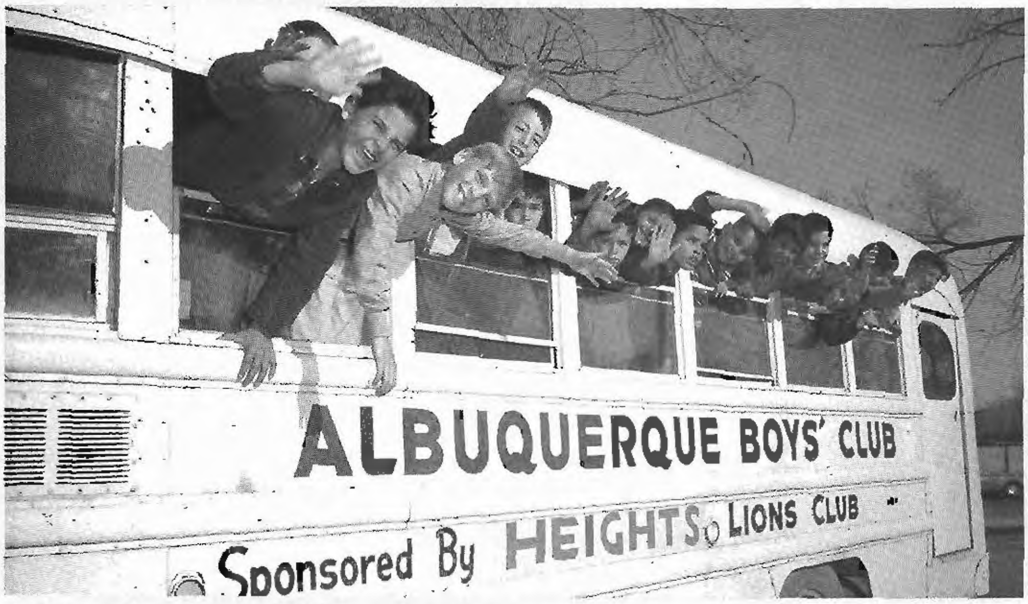
President Hornbeck explains requirements to an affirmative action committee.

END OF THE DECADE

Sandia ended the 1960s with solid accomplishments marking its history during the decade. It established programs implementing the four LTBT safeguards demanded by Congress in 1963. It participated in design and testing of weapons ranging from the B61 to the warheads for Minuteman and Poseidon missile systems and the Safeguard antiballistic missiles, and initiated exploratory programs for miniaturization and new weapons development. It focused attention on enhanced nuclear safety as well, meeting the stringent requirements set in 1968 within a few years.

To comply with the safeguard requiring the maintenance of vigorous laboratories, Sandia diversified, providing support for conventional warfare in Vietnam, for space power safety, and for intelligence activities. It built these reimbursable and special projects into a program providing a significant part of its budget.

The advent of computer modeling further reduced the need for empirical engineering, and Sandia's research produced new understandings of tritium, ferroelectric ceramics, shock wave physics, ion implantation, radiation damage, and blast effects. Out of Sandia's exploratory weapons programs came the new science of terradynamics and from its participation in the VELA program developed new understandings of gamma-ray astronomy. Truly, by 1969 it had earned the title Sandia Laboratories.



ECP sponsored projects large and small. New windows for this Albuquerque Boys Club bus were purchased with a portion of the 1964 Employee Contribution Plan reserve fund.

ECP and LEAP

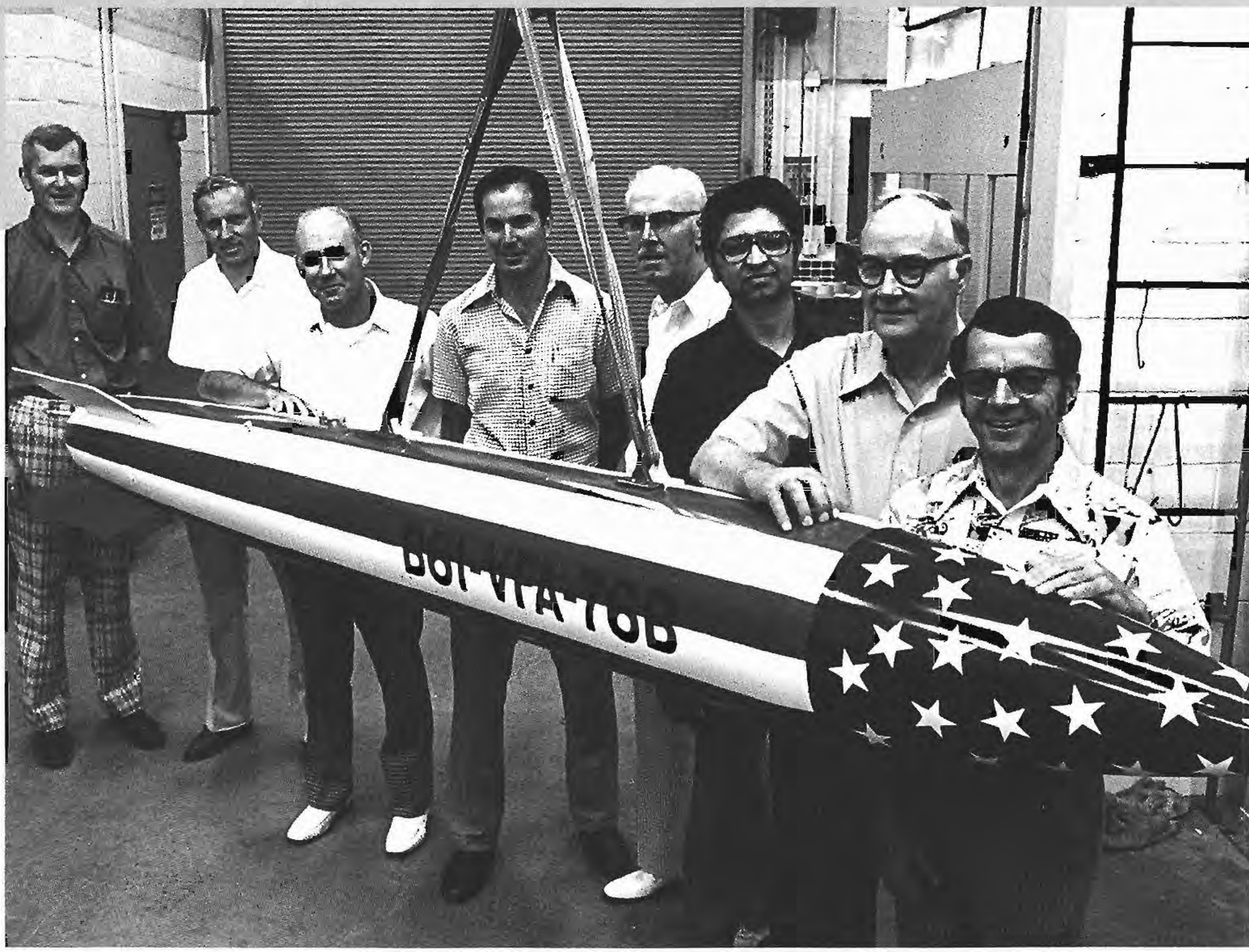
Sandians have always generously supported community service organizations, both in Albuquerque and Livermore. In the 1950s contributions were solicited through annual drives and the first one netted some $10,000. Sandia's Employee Contribution Plan (ECP), which introduced payroll deductions, began operating in the fall of 1957. Employee contributions dramatically increased 35 percent over the previous year. That giving represented about 20 percent of the total pledged to the United Way in Albuquerque that year — a level of support that has continued through the years.

Sandia California began its own campaign in 1969 called LEAP (Livermore Employees Assistance Plan). Agencies that shared in the $160,000 collected in 1995 were located all the way from the Livermore Valley to the Bay Area.

Ted Sherwin, manager of the Public Relations Department until he retired in 1981, reminisced about ECP:

ECP — or the program that became ECP — did not happen overnight. It took four or five years to get it started. I began waging a memo-writing campaign in 1953 to get formal approval for major changes in the way our employees could be solicited by charitable organizations and how they could make contributions to these groups ... Back then, employee giving was based on parent-company practice. First, it was limited to United Way, which was called the Community Chest, and to the Red Cross. We were getting a lot of pressure from ... mostly the national health agencies, that weren't supported by United Way. They wanted, and justifiably so, to solicit Sandia employees ... Year-round giving by payroll deduction would be the key. That was new in those days. Also, we didn't want to second-guess the community on how to distribute ECP funds. We'd rely on existing community-giving patterns ... There were lots of meetings, lots of extra hours ... but we finally got the program through ... Even after all these years, I've never heard anyone say we made the wrong decision with ECP. I remain very proud of our work, especially in the fall, when I read how much Sandians are pledging to their community, both in money and time.

In 1995, Sandia employees pledged over $1.4 million, with 99 percent of that amount earmarked for the United Way.



A Sandia testing group in 1976 next to a patriotically painted B61 test unit. *Left to right:* Bob Martin, Leland Stone, Dale Buchanan, Jim Lohkamp, Dale Massey, Pete Hernandez, Phil Young, Larry Johnson.

V

THE MULTIPROGRAM TRANSITION

The weapons laboratories represent a combination of trained manpower and physical resources that is available nowhere else in the West. The laboratories also make a major contribution to U.S. energy programs and to basic scientific research in general. It would be extremely difficult if not impossible to reassemble this complex in a crisis situation.

Edward Giller

Although it worked in such related fields as satellite and seismic detection of nuclear testing, Sandia had remained essentially a single-mission laboratory since it was established in 1949. This situation ended during the early 1970s, when it experienced three personnel reductions, shrinking its staff by twenty-two percent from more than 8,000 to 6,500. At this critical juncture, Sandia's management led mission expansion into new research and development arenas where it enjoyed considerable success.

While navigating this period of profound change, Sandia undertook major nuclear weapon design projects and continued exploring advanced weapons. In addition to traditional weapon programs, the national interest turned to needs for improved nuclear reactor safety assessment and greater physical security. And when national priorities emphasized energy during the 1973 oil embargo, Sandia stepped up its explorations of energy technology. As a result, by the time of the national bicentennial in 1976, Sandia had become a multiprogram laboratory of the Energy Research and Development Administration (ERDA).

TAILORED WEAPONS

As Sandia's weapon development entered the 1970s, the earlier emphasis on quickly increasing the size or yield of the nuclear stockpile abated. "From high-yield weapons," observed Bill Spencer, "we went to weapons tailored to a particular job or to weapons suitable for use in a variety of operational situations." Moreover, this new phase coincided with the end of the antiballistic missile program. When the basic Safeguard antiballistic missile system was completed in 1974, Congress terminated its production and operation.

"Miniaturization and flexibility — in the nuclear weapons business, the two go together," observed Glen Otey, commenting on the new approaches to nuclear weapon design. For example, the arming, fuzing, and firing package completed in 1970 for the Navy's Mark 3 reentry body set new standards for miniaturization. Using microelectronics and clever packaging, the Sandia design team produced small radars, neutron generators, power supplies, and firing systems with all the capabilities of larger systems and with far greater protection — hardening — against defensive countermeasures. So small was Sandia's package for the Poseidon warhead that it fit into the nosetip of the reentry body, moving the center of gravity forward and improving the reentry body's stability.

Successful completion of designs for the Poseidon (W68) and Safeguard (W66 and W71) warheads brought those programs to an end, and in 1973 Sandia also ended development of two artillery-fired atomic projectiles for battlefield deployment. The Army planned to use these nuclear shells, designated W74 and W75, in its 155-millimeter cannon and 8-inch howitzer for theater defense.

Harold Vaughn, an applied mathematician, developed the theory of ballistic matching between a conventional high explosive and a nuclear shell. When Harold Agnew of Los Alamos was briefed on this theory he became very enthusiastic about a W74 (155 mm) phase 3. John Hornbeck was so impressed with this theory that he borrowed Vaughn's viewgraphs and regularly briefed his VIP visitors on ballistic matching. Department of Defense official and ex-Sandian Don Cotter's observations indicated the very threat of atomic projectiles and other theater nuclear weapons had salutary thinning effects on opposing forces in Europe: facing nuclear weapons, Warsaw Pact troop concentrations declined substantially. Concerned about the costs of these nuclear shells, however, Congress slashed them from the budget in 1973, although it later approved programs for the design of other nuclear artillery shells.

In the face of shrinking nuclear weapons budgets, Sandia considered ways to use existing weapons or their components in new configurations. Studies began, for example, on using subsystems of the B61 bomb in warheads for cruise missiles, in Pershing II missiles, in depth bombs, and in an extended range bomb. Using the B61 as a building block for new systems could bypass the need for testing new nuclear systems while also reducing development time and cost. For the W72 nuclear warhead to be used

Director of Military Applications General Ernest Graves and Assistant Secretary of Army Norm Augustine in 1974 examine the arming, fuzing, and firing Poseidon module held by Morgan Sparks.

Chris Dalton and Harold Smith work at an extended range bomb with a propulsion system that could take it to a target after release from an aircraft.

The Lance (W70) tactical missile, seen here with its erecting launcher, was deployed to Europe.

Don Shuster displays a model of the extended range bomb under study during the 1970s.

on the optically guided Walleye missile, for example, Sandia adapted the arming and firing systems of the B61 that were already in production, thereby meeting tight schedules and minimizing costs.

After winning a design competition on nuclear payloads for the Army's Pershing II theater missile, Ray Reynolds, Bill Alzheimer, Bill Hoagland, and Sam Jeffers led Sandia teams that designed two warheads, the W85 for air-bursts and the W86 for earth penetration. For the W85, Sandia's team adapted design features of the B61, shortened its case, and replaced its arming and fuzing system with components supplied by the Army. Although Congress ended the W86 earth penetrator program for budgetary reasons, Sandia completed development of the W85 air-burst/surface-burst version, and the Army deployed it on the Pershing II in 1983.

To tailor weapons for tactical use during the 1970s, Sandia adopted computer graphics to better simulate battlefield situations. Sandia's systems studies group also applied computer wargaming to assist in analyses of

John Hornbeck, Air Force Lieutenant General Sam Phillips, and Robert Kraay in 1971 examine one of the advanced nosetips developed by Sandia for reentry vehicles.

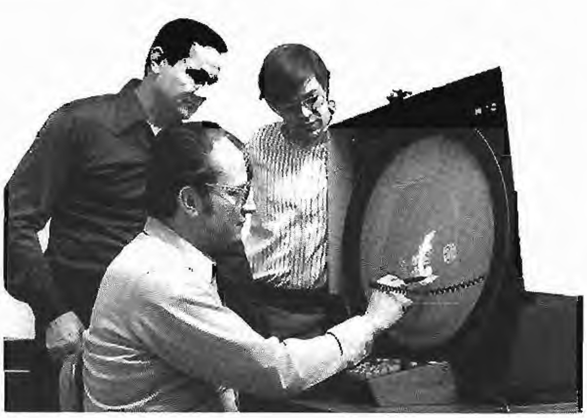
the potential deployment and uses of nuclear weapons. "Wargaming is a tool for investigating how a tactical conflict may unfold," asserted Garry Brown. "It can illustrate battlefield situations that call for special measures — for example the employment of nuclear weapons to neutralize heavy armor yet not destroy the countryside in the process."

The U.S. Space and Missile Systems Office sponsored several Sandia exploratory programs such as the development of carbon-carbon nosetips. Glen Otey, Virgil Dugan, and Curtis Hines managed the Allspice study of retrofitting missile reentry vehicles with the maneuvering capability needed to get past improved surface-to-air missile defenses. This "bolt-on" capability would add to reentry vehicles a guidance system, motors for pitch and roll control, plus pitch flap and roll-control thrusters that would allow them to take evasive actions during their approaches to targets. After concluding that Allspice could permit penetration by reentry vehicles past even multiple surface-to-air missiles, the Sandia team delivered its systems study in 1972, but the Air Force did not pursue the concept.

Sandia's Jigsaw studies and flight demonstrations of the 1970s sought to advance electronic battlefield concepts through added precision in tactical battlefield weapons. If electronic guidance systems could provide higher delivery accuracy, warheads with lower yield could destroy targets and reduce collateral damage as well.

Tom Edrington explained that the Jigsaw program considered several concepts, each named for a coin: Baht, Kopeck, Threepence, and so forth. Baht involved planting a beacon on such targets as bridges and then firing a tactical missile to home accurately on the beacon. Because the Baht concept required that special forces plant the beacons on heavily defended targets, Kopeck concentrated on developing an offset beacon, actually a small tracking radar with a transmitter that could issue course-correction guidance to missiles. Placed in the vicinity of, rather than on, a target, Kopeck could track a missile and adjust its course for a precise strike; Don Shuster called it a "magic wand" that could wave missiles precisely to the targets. Threepence utilized three less-complicated beacons to provide similar delivery accuracy.

Sandia initiated its Tactical Inertially Guided and Extended Range (TIGER) bomb program in 1972. Delivering free-fall or parachute-retarded bombs required that aircraft fly over targets and encounter the



A systems studies team of Norm Breazeal and Garry Brown observes Dick Basinger at a computer graphics screen used in 1976 for evaluation of weapon options and delivery systems.

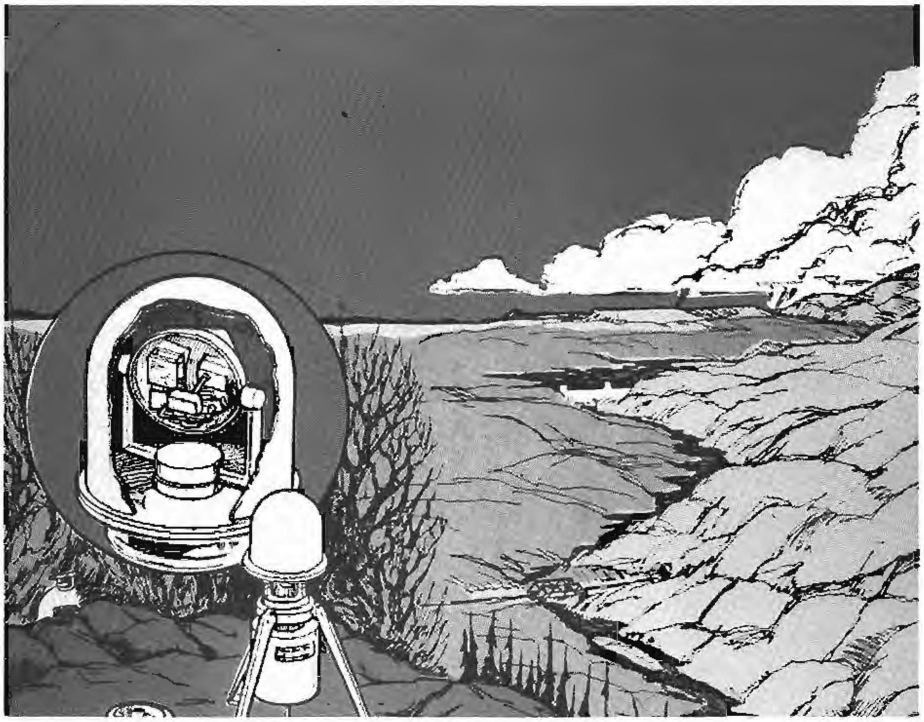
In 1976, Sandians deploy an experimental parachute developed for the B61. *Left to right:* Alvin "Oley" Oleson, Bruce Ercole, Bill Pepper, Harold Widdows, Ernie Hall, Dennis Cronin.

threat of hostile defenses. "If you can't fly to the target on the deck the probability of completing the mission is fairly low," said designer Chris Dalton, explaining that an extended range bomb "would greatly increase the probability of a successful mission by allowing the aircraft to release the weapon some distance from the target and at a very low altitude."

This required a rocket-boosted system for low-level delivery. To maintain delivery accuracy comparable to that of laydown bombs, Sandia also incorporated a radar altimeter to measure terrain profiles and continuously update the inertial navigator to minimize error rates. The resulting extended-range bomb could be launched at greater ranges, providing less exposure to hostile defenses; moreover, if the aircraft passed over a mobile target, the crew could release the extended range bomb to return to the target. "He can fly next to the target and deliver the weapon to it," explained Charlie Winter, "or after he's flown over the target, he can have the weapon circle around and detonate over the target so he doesn't have to come back."

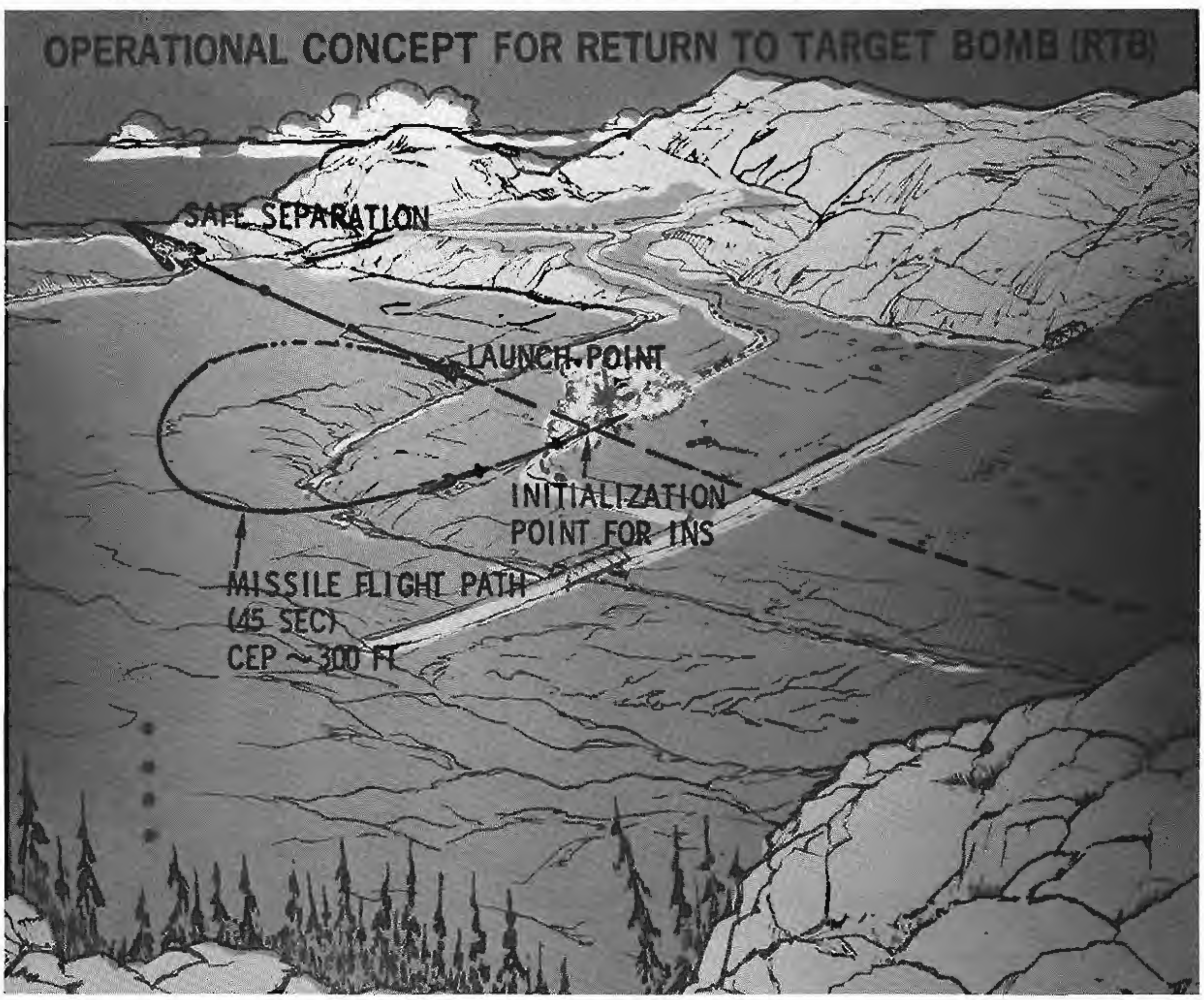
Sandia designed a conversion kit, adding nose canards and tail surfaces, a rocket motor, flight computer, inertial navigation system, radar altimeter, and related equipment as a retrofit for existing bombs, particularly the B61, to provide a relatively inexpensive means of providing an extended range capability. Sandia successfully tested its extended-range bomb at the Tonopah range during the late 1970s; although pilots strongly approved of them, they did not receive full development authorization. "To me," reflected Heinz Schmitt, "it still is one of the more unique capabilities that we should have built."

The TIGER concept was a very complicated design and challenged the capabilities of the aerodynamics department. Harold Vaughn and Jerry Wilson mathematically modeled trajectories and conducted wind tunnel tests. The guidance system was tested in real time on the aerodynamics department's flight simulator, which consisted of analog/digital computers connected to a 3-axis motion simulator platform.



Left: Illustration of the Jigsaw-Kopeck concept of planting a portable guidance system near a target (bridge over river below) to guide missiles directly to the target.

Below: This drawing illustrated the return-to-target bomb concept. After passing the target, the aircraft could release the bomb and it would circle back for the strike.



Interest in achieving improved delivery accuracy for exploratory projects such as TIGER encouraged further research on guidance systems at Sandia. During the 1960s, defense contractors had adopted a terrain-scanning radar for use in cruise missiles. This system stored the terrain contours — a map — of a flight path, then periodically located itself by comparing radar profiles of terrain along its path with the stored map to correct its course. Between checks against the map, it navigated inertially. Studies of better guidance systems proceeded in systems groups managed by Tom Edrington and Ron Andreas during the 1970s, culminating with the development in 1975 by Larry Hostetler and associates of the Sandia Inertial Terrain-Aided Navigator (SITAN).

Rather than providing periodic position checks as in earlier systems, SITAN operated continuously, guiding a weapon all the way to its target. Using Hostetler's computer algorithms, it continuously combined inertial and altimeter data to obtain the vehicle's position along with its velocity and altitude to determine course corrections. Sandia successfully tested SITAN at the Edgewood test range in 1975, and continued its research with Air Force cooperation, finding applications for the system on aircraft, helicopters, and land vehicles.

FUNDING AND STAFF RETRENCHMENTS

When President Richard Nixon orchestrated a national belt-tightening in 1970, budgetary restrictions for the AEC forced Sandia to implement its first significant reduction in force in a decade. Although described merely as a "trimming," it worried the Albuquerque community, which had grown accustomed to expansion or stability at Sandia. "If it continues for two or three years, it will have significant impact," Sandia vice president Ray Powell admitted to reporters. New Mexico Senator Clinton Anderson, of the Joint Committee on Atomic Energy, responded with a warning that the 1963 LTBT safeguards mandated vigorous programs at Sandia and its partner laboratories and further reductions "could jeopardize the safeguards."

From 1970 to 1974, national budgets for research and development declined by nearly a third. These reductions were passed on to the national laboratories. However, during this same period, Sandia's engineering development projects remained virtually constant, and many of its budget reductions therefore fell on its exploratory and advanced development programs. After the 1970 layoff and another significant personnel reduction in 1971, Sandia leaders became increasingly concerned about the future and became interested in pursuing opportunities outside the nuclear weapons program. Two events in 1972 gave urgency to such work: the commercial nuclear reactor emergency core cooling systems hearings and the massacre of Israeli athletes at the Olympics in Munich.

In response to public criticism of interim safety standards for commercial nuclear reactors, AEC Chairman James Schlesinger convened hearings on these standards in 1972. These hearings continued throughout the year. As they progressed, Schlesinger and his deputies concluded that increased knowledge of reactor design safety was needed.

Although Sandia had designed and built nuclear reactors for its own materials and weapon effects testing, it had not participated in the design or promotion of commercial power reactors. It had broad experience in weapon safety design and evaluation, nevertheless, and had performed safety assessments for the SNAP space power systems. AEC officials and consultants such as Norman Rasmussen visited Sandia in 1972 to examine facilities and capabilities that might be used for an independent examination of nuclear reactor safety issues.

Bob Peurifoy agreed on the importance of such a mission, because "the possibility of a serious accident with a nuclear power reactor was perhaps almost as catastrophic as an accidental nuclear detonation." A group, including Peurifoy, Bill Nickell, Don Lundergan, and others, reported favorably on

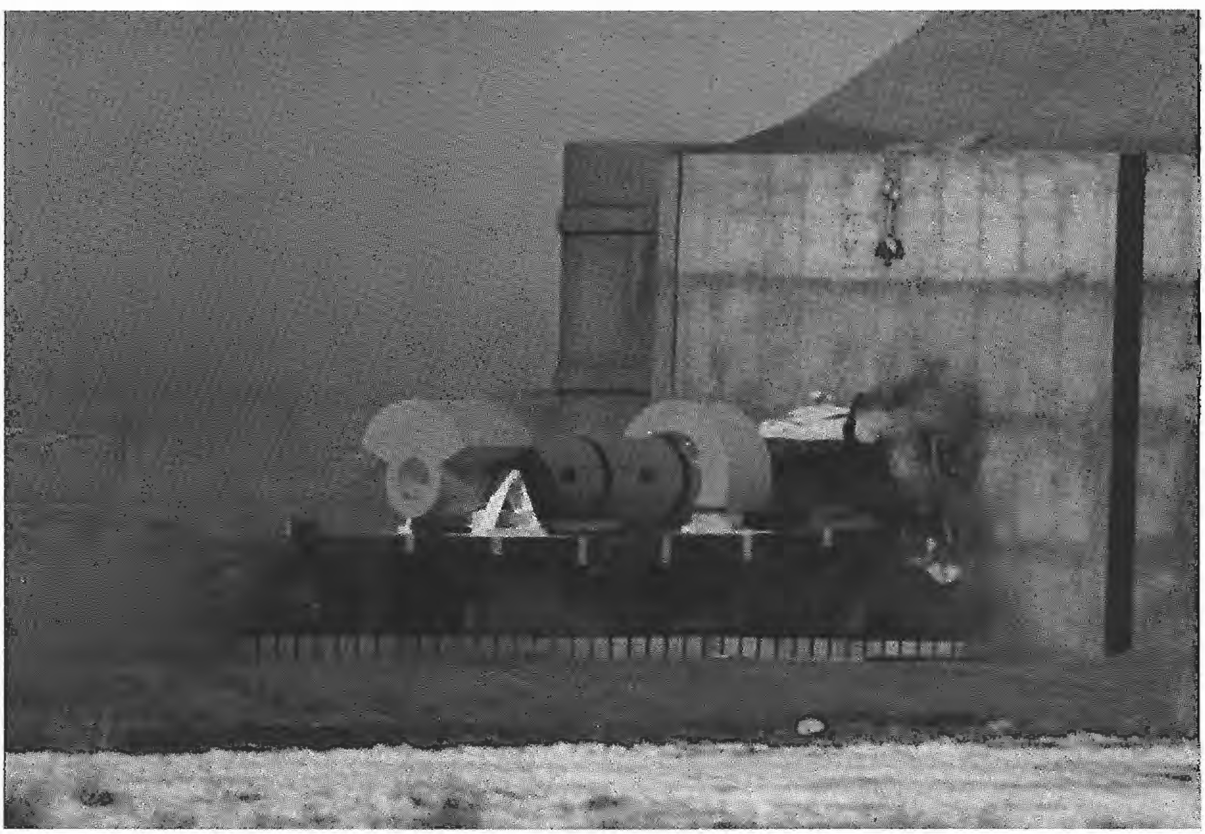
Sandia accepting a nuclear reactor safety mission and prepared proposals for the AEC reactor safety division.

Sandia received its first funding for reactor safety investigations in early 1974 and formed a nuclear fuel cycle directorate headed by Bill Snyder. One of its first missions was to conduct a study to complement the newly published reactor safety study (referred to as the Rasmussen Report). The Sandia study investigated the potential of malevolent attacks (overt and covert) for release of radiation to the environment.

Perhaps the most spectacular aspects of this new research were the environmental tests managed by Bob Jefferson and Bob Luna. The media devoted great attention to the tests of accident-resistant casks for transporting nuclear wastes, which involved ramming locomotives into trucks, or smashing trucks carrying the casks into walls at eighty miles an hour. Less spectacular but equally interesting were Sandia's materials and processes investigations. As early as 1974, Dick Lynch and Dick Schwoebel reported progress in using ion exchangers to separate radioactive solids, which then could be heated and pressed to form stable ceramics. Patented by Robert Dosch, this solidification process could separate cesium, strontium, and transuranic elements from low-level wastes for easier disposal. Research on the nuclear fuel cycle expanded further during the late 1970s, especially the technical support for efforts to identify and characterize the nuclear waste disposal sites that are described in later chapters.

SAFEGUARDS AND SECURITY

Sandian Andy Lieber declared that the 1972 massacre of Israeli athletes at the Munich Olympics "marked the beginning of

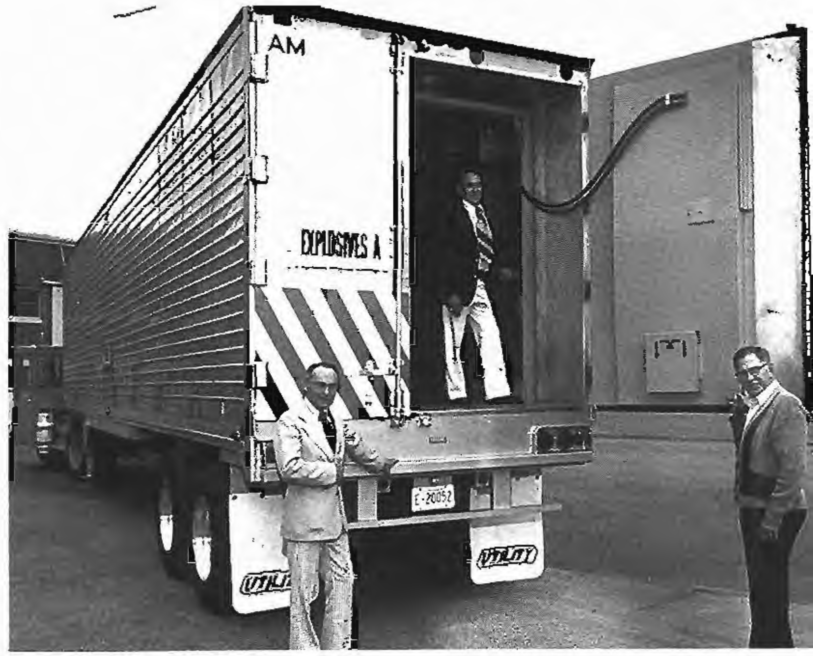


During the 1970s, Sandia tested shipping casks for spent nuclear fuel by ramming them and their truck transports at high speeds into concrete walls. This cask survived the impact.

modern concerns and approaches to nuclear weapons security" by emphasizing the fact that security forces might be confronted by bands of heavily-armed terrorists. Orval Jones noted that interviews with nuclear weapon designer Ted Taylor, published in 1973, implied that terrorists might make a crude nuclear explosive or radioactive dispersal device if they were able to steal special nuclear materials. This "caused the nation to undertake a thorough reanalysis of vulnerabilities and upgrading of its nuclear safeguards both for weapons and materials."

Sandia's initial interest in physical safeguards and security, however, may be traced to a 1967 panel report to the AEC on safeguarding nuclear materials and to the work of a review committee that followed. In 1968, Bill Stevens represented Sandia on a joint AEC-DoD committee that recommended enhanced safeguards, including measures during transport, for combating terrorist threats that might divert nuclear materials. In 1970, Richard Petersen, with assistance from Ed Roth and others, designed a Safe Secure Trailer (SST) for transporting nuclear weapons. To replace the commercial highway transport then used, the design called for the use of these special highway trailers with thick walls, further protected by devices to deter unauthorized entrance. Moreover, Sandia's studies recommended use of the AEC emergency radio network to maintain constant communications with the truck-trailers in transit.

In 1971, Sandia advised General H. C. Donnelly, manager of the AEC Albuquerque office, of its capabilities to build a prototype SST. After Sandia completed the prototype Donnelly ordered further production. A full-scale development and production program, managed by Gene Blake, provided a number of operational vehicles that were used by the AEC. Tom Sellers and Jim DeMontmollin then planned a system to maintain constant radio contact between dispatchers and the SSTs anywhere in the United States. This system, which used computerized data handling and multi-channel radio transmissions, was developed and tested for the AEC division of nuclear materials



Robert Reed, Loren Bishop, and James Taggart point with pride to Sandia's safe and secure transport (SST) for the movement of nuclear materials.

In 1974 Sandia tests an accident resistant container model in Building 840. Such containers were designed to protect nuclear materials during transport.

Sandians in California brief General Joseph Bratton, Division of Military Applications, and General Alfred Dodd Starbird, ERDA Administrator for National Security, in 1976. *Left to right:* Byron Murphey, Walter Bauer, Dan Hartley, Bratton, Tom Cook, Starbird.

security. Later, as SECOM (secure communications), it was placed into operation by the Albuquerque Operations Office for monitoring shipments of nuclear materials, weapons, and components.

In 1974, largely as a result of the four-year-long Sandia study known as the Nuclear Weapon System Safety Hazard Evaluation Group, the AEC decided to move all completed weapons and nuclear materials in SSTs. Gene Blake and Jim Jacobs led the crash effort to provide the required equipment and system tools. Later, Sandia designed new SST models, and during the 1980s Jim Baremore and Neil Hartwigsen worked with Randy Sabre of DOE's Albuquerque office to design an improved safeguards transporter to implement modern safety features. The SST supplanted air and rail as the preferred transport mode for nuclear weapons and materials within the United States.

Concern about potential acts of nuclear terrorism also focused attention at both AEC and Defense agencies on the security of weapon storage sites and other installations. Receiving assignments from the AEC, Sandia formed a nuclear security systems directorate under Orval Jones and began developing electronic detection and access denial systems for better protection of the storage sites in addition to implementing the secure transportation system.

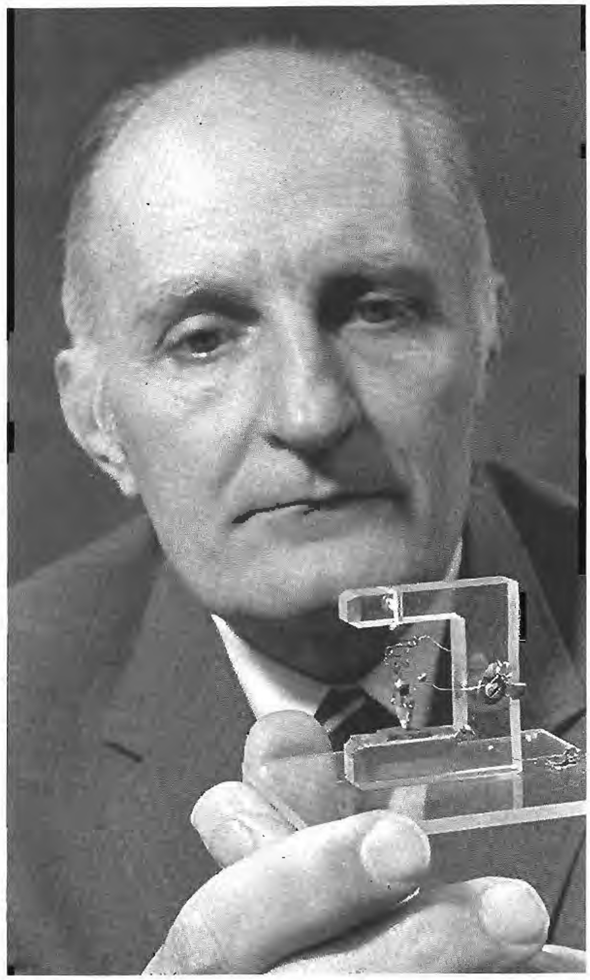
Although totally preventing entry to a site by a well-equipped and determined force was impractical, analysis showed that entry could be slowed enough by multilayered security to permit guard forces to respond. Site defenses began with fences and sensors to alert guard forces to a penetration attempt. Within the fences would be earth berms or obstructions to force the abandonment of vehicles and the hand-carriage of equipment to the next obstacle — reinforced-concrete walls. If the invaders penetrated the concrete walls, then they confronted obstructions to further delay their operation. "The goal," Ira White explained, "is to slow down the adversary, to escalate the problems, to keep the clock ticking ... ticking ... ticking."

"We can look at the complete problem — from paper design through hardware development to proof testing," said Bill Myre, who succeeded Jones as safeguards manager. "It's the same approach that has proved so successful in the development of weapons." For example, Ted Gold and Rob Rinne of the systems studies group applied their experience with war games to evaluate truck convoy security, devising "Ambush" and "Skirmish" games as teaching tools. "We can better understand combat among small forces and some of the human factors," said Rinne, explaining how the games assisted convoy defense teams seeking better understanding of their missions. Bob Wilde led the development of the military-integrated laser engagement system for realistic field training using actual security guards and simulated attackers.

Both the safeguards and the reactor safety assessment programs at Sandia grew throughout the 1970s. Safeguards funding, for example, increased from $8.9 million in 1975 to $24.5 million in 1977. Yet neither assignment had progressed sufficiently to ameliorate the 1973 reduction in force.

THE LAYOFF

When John Hornbeck returned to Bell Laboratories in September 1972, Morgan Sparks became Sandia's president. After joining Bell in 1943, Sparks had been a member of the research group that launched the age of semiconductors and made the first junction transistor, a device that spawned industries worth billions. While "the industrial revolution was an extension of



Morgan Sparks made the first junction transistor at Bell Laboratories and became Sandia president in 1972.

Morgan Sparks in March 1973 answers questions from newsmen about Sandia's major reduction-in-force.

GETTING THE NEWS OUT

Lab News staff gather with new editor, John Shunny, in 1969 to review the fruits of their labor. Top row: John Shunny, Don Graham, Gerse Martinez. Second row: Bill Laskar, Norma Taylor, Cherry Lou Burns. Front: Don Wolfe.

Sandia *Lab News*

Circulated in-house every other Friday since 1951, the *Lab News* has gained a niche in employees' affections. As a company newspaper, it deals with a unique challenge: how do you talk about the company product when that product is a highly classified nuclear weapon?

Early editors — Bob Gillespie, Bob Colgan, Tom Heaphy — avoided the issue. By fiat. So sensitive was the subject in the 1950s that each draft was read aloud by Superintendent Harold Sharp to President Landry, cover to cover, bowling scores and all. "Strike that!" Landry would exclaim, and the reading continued. Under this regimen, the *Lab News* was long on news of employees' activities in the community, hobby stories, and Coronado Club activities, but short on "hard" news of weapon programs.

By the late 1960s, AEC was relaxing its restrictions. John Shunny (editor, 1968-1982) recalled:

We could actually refer in print to, say, the Mark 28 and identify engineers working on the program. Later, photos revealing the external appearance of various weapons were permitted.

The beginning of the modern and more open Lab News *can be dated to December 1970, when President John Hornbeck consented to a state-of-the-Labs interview, to be published in January (and a tradition ever since). Short of information actually classified, Hornbeck went along with the no-holds-barred format, a startling (at the time)* démarche *when compared to his predecessors. During the 1970s, articles on weapons and components, field tests, materials research, and other weapon-related activities became commonplace in the* Lab News. *This openness continues today and includes as well a remarkable candor on how the business is being run.*

muscle, through a controlled use of energy," Sparks explained, "the electronics revolution is an extension of the mind — new means of communications, and computers that aid in calculations, thought processes, decisions, automatic controls, etc."

Sparks arrived at Sandia a few months before the largest cutback in its history. Meeting with James Schlesinger and Edward Giller at AEC headquarters for a briefing on the reductions mandated by the Office of Management and Budget in 1973, Sparks asked Giller if Sandia should pursue reimbursable projects to challenge its weapon engineers during lean times. Giller pointed out the irony that after Sandia backed out of technical administration of the space power program, Los Alamos had accepted that work, creating seventy new jobs there. He offered support for diversifying Sandia's missions, but warned that the military applications division would not help Sandia when funding from other AEC divisions declined.

The last AEC chairperson, Dixy Lee Ray, and her pets pose with General Harold Donnelly of the AEC Albuquerque office and John Hornbeck of Sandia.

In January 1973, Sparks announced a ten-percent staffing reduction that would be accomplished by the end of June. John Shunny, editor of the *Lab News*, termed this a "soul-searing experience" for those remaining as well as those who left. "It was a very traumatic experience followed by lawsuits," commented Arlyn Blackwell later, "and the memory of that agony still remains." Although Sandia's management thought it made the layoff selections with an even hand, successful litigation against Sandia by former employees and the Department of Labor, charging age discrimination, followed the reduction and continued for more than a decade.

When reporters asked how Sandia should regroup for the future, New Mexico Senator Joseph Montoya responded that it should tell its story "to the American people, not just to a congressional committee." Administrative vice president Charles Campbell replied that Sandia should not rest on its laurels, "We've got to let the world know we're here and can do good technical work." Morgan Sparks explained that Sandia planned to seek new programs "to add stability to our future workload and to provide diversity in our technical programs."

ENERGY INITIATIVES

When amending the Atomic Energy Act in 1971, Congress authorized AEC research on "the preservation and enhancement of a viable environment by developing more efficient methods to meet the Nation's energy needs." To meet this mandate, Dixy Lee Ray, the last AEC chairperson, encouraged the AEC laboratories to devote resources to energy research and appointed a committee to plan future national energy policies. Don Shuster represented Sandia on

New Mexico Senator Joseph Montoya visits Sandia in 1973. *Left to right:* Newsman John Shunny, Morgan Sparks, Montoya, Ray Powell.

Ray's policy study committee, and informally began to explore how energy research might match the capabilities developed in Sandia's weapons programs. Jim Scott, Orval Jones, and other Sandia leaders met in Shuster's office daily during late 1972 and 1973 and solicited ideas and proposals for energy research from throughout the Laboratories.

Sandia's sunny southwestern location sparked interest in solar energy, and in October 1972 the Shuster team sent a proposal drawn up by Bob Stromberg to the National Science Foundation, then in charge of federal solar energy research. It called for experimental development of a "solar community" engineered to obtain essentially all its energy from the sun. Because this proposal would have taken more than half of the funding then available nationally for solar research, the Foundation rejected the proposal but approved a $100,000 feasibility study — the first funding for energy research at Sandia.

Additional funding for the solar total energy experiment came in 1974, and Sandia constructed a pilot project to investigate heating water with solar collectors, storing the water underground in insulated tanks, and using heat from the water to drive turboelectric generators and provide power for air conditioning, heating, and hot water. Senator Joseph Montoya broke ground for the project, which produced its first electricity in 1976. Managed by James Leonard, the solar total energy facility became a test bed for the solar collectors and photovoltaic technology designed by private industry and by Sandia.

"The proposals run the gamut from an ingenious technique for coal excavation to the use of wind as an energy source," said Shuster, Sandia's energy coordinator, of the twenty-one project proposals he forwarded to the AEC in 1973. "It is important to note that Sandia didn't jump onto every bandwagon labeled 'energy'," he pointed out, adding that the energy project proposals had to meet three criteria: Did the project exploit the technologies and talents Sandia had amassed in weapon programs? Was the project innovative and ahead of the pack? Would it really decrease the nation's dependence on foreign oil?

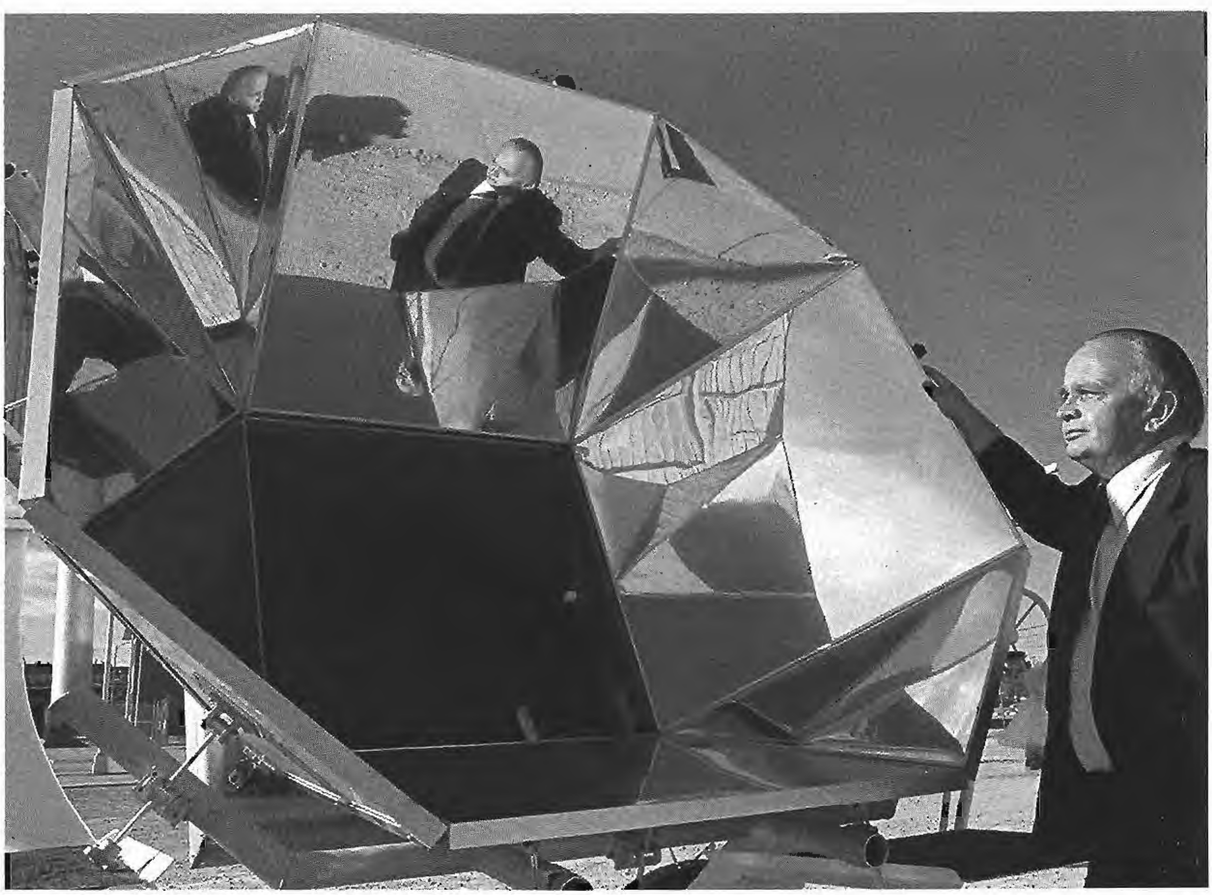
Observing that energy then was a "hungry market," Shuster asserted that Sandia could provide the concentrated effort and proven systems approach that had served national weapons programs so well. "The country needs both nuclear and non-nuclear work," he said, "and we're going to help meet that need."

AN ENERGY CRISIS

The 1973 energy crisis focused national attention on energy resources. Subsequent formation of the Energy Research and Development Administration (ERDA), uniting national nuclear energy programs together with other federal energy initiatives, brought top level support for Sandia's energy research.

On the heels of the 1973 Yom Kippur War in the Middle East, the Organization of Petroleum Exporting Countries slapped an embargo on oil shipments to the United States, and higher bills for electricity, home heating, and gasoline followed. This immediately generated public interest in alternative energy sources. "In no time flat, we learned a valuable lesson," recalled Bob Peurifoy, "over-dependence on foreign fuel supplies was a crisis in the making."

As disgruntled Americans lined up at filling stations to purchase gasoline, President Richard Nixon directed federal agencies to curtail energy use by at least seven percent annually. Energy coordinator Don Shuster and a task force led by Harry Pastorius reduced heating and lighting throughout the Laboratories and trimmed vehicle usage. In November 1973, Sandia joined the AEC Albuquerque office and the Air Force at Kirtland in shortening their employee lunchtime from an hour to a half-hour, thereby preserving a synchronized schedule,



Sandia energy coordinator Don Shuster in 1973 examines an early solar energy collector design.

During a 1975 visit to Sandia, ERDA Administrator Robert Seamans listened to Jim Leonard describe experimental solar collectors.

shortening daily utility use by thirty minutes, and conserving gasoline by reducing noon-hour driving. Shuster estimated that the shortened lunchtime resulted in saving 261,000 gallons of gasoline yearly. To further reduce energy consumption, Sandia named the Friday after Thanksgiving as an energy conservation holiday, and closed the Laboratories, except for security and essential staff, during the week between Christmas and New Year's Day. By these and similar measures, Sandia reduced its total energy consumption by twelve percent during 1974, achieving additional reductions during later years.

The 1973 oil embargo and energy crisis, as well as growing public criticism that the AEC had a conflict-of-interest in both promoting nuclear reactors and assuring their safety, encouraged the enactment in 1974 of legislation abolishing the AEC and transferring its functions to two new agencies, the ERDA and the Nuclear Regulatory Commission (NRC). Although this was a Nixon administration initiative, Nixon's resignation in August 1974 elevated Gerald Ford to the Presidency and Ford signed the bill creating the new agencies later that year. The NRC assumed the AEC regulatory responsibilities for commercial nuclear reactor safety, thereby becoming the funding agency for Sandia's reactor safety assessments. AEC responsibilities for weapon and energy research went to ERDA, which also acquired fossil fuel research from the Department of Interior, solar and geothermal research from the National Science Foundation, and automotive propulsion research from the Environmental Protection Agency.

The first ERDA Administrator, Robert Seamans, had visited Sandia earlier while serving as Secretary of the Air Force; he understood the Labs' capabilities, and he returned twice during 1975. A provision of the law creating ERDA directed Seamans and the Secretary of Defense to study transferring the weapon programs that ERDA had acquired from the AEC to the Department of Defense. Seamans assigned this study to his Assistant Administrator for National Security, General Alfred Dodd Starbird, with Gordon

Moe, a former Sandia systems studies expert, serving as action officer. When Seamans and the Secretary of Defense reported in 1976 that nuclear weapon programs should remain an ERDA responsibility, President Ford agreed and recommended that ERDA's defense programs be reviewed again in a few years. The second review occurred in 1979, and similar reviews by various committees continued thereafter at about five-year intervals.

The transition from the AEC to ERDA, with its expanded energy responsibilities, opened new opportunities for Sandia. Approval came during 1974 and 1975 for investigations of tapping the energy of magma, of wind energy, of drilling technology, of recovering solar energy by diverse means, of coal gasification and oil shale retorting, and of other potential energy sources. To staff these new programs, Sandia transferred weapon systems analysis staff such as Virgil Dugan and Sam Varnado and exploratory weapon staff such as Max Newsom into energy research. Morgan Sparks relied on Don Shuster in Albuquerque and Arlyn Blackwell at Livermore for the broad review of Sandia's energy initiatives. He depended on Hap Stoller in fossil energy, Bill Snyder in environment and reactor safety, and Al Narath for solar, geothermal, and advanced energy research. In 1975, Narath's vice presidential responsibilities were enlarged to include an energy projects directorate headed by Jim Scott, with Glen Brandvold managing advanced energy, Stoller in charge of geoenergy, and Dugan presiding over systems analysis.

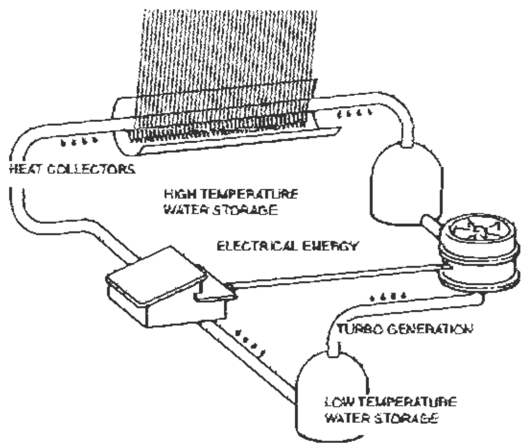
SOLAR THERMAL

Collecting the sun's rays and focusing them to produce useful high-temperature, thermal energy became a high-profile activity at Sandia during the 1970s. Tom Brumleve in Livermore and Jim Banas and Bob Stromberg in Albuquerque initiated Sandia's research on two solar thermal technologies: central and distributed receivers.

Left to right: Herman Roser, manager of the ERDA Albuquerque office, and Robert Seamans, ERDA Administrator, are escorted by Morgan Sparks during their 1975 visit to Sandia.

The central receiver concept involved mounting a receiver or boiler on top of a tower, heating it with concentrated sunlight reflected from a field of sun-tracking mirrors (heliostats), and using the steam to generate electricity for public utility service. Sandians in California, where a ten-megawatt central receiver named Solar One was planned at Daggett, near Barstow, took leadership in this technology, while Sandia's Central Receiver Test Facility for experimentation was constructed south of Sandia in Albuquerque. Selected in 1975 as ERDA's technical administrator for central receivers, Sandia began building its experimental five-megawatt "power tower" test facility under the leadership of John Otts and Billy Marshall. The power tower began operating in 1977.

Al Skinrood and colleagues at Sandia managed multi-million dollar contracts for the competitive design and construction of Solar One from 1975 to 1982. Solar One, the first commercial solar-electrical generation plant in the nation, operated reliably from 1982 to 1989, when planning began for the advanced Solar Two facility that opened in 1996.



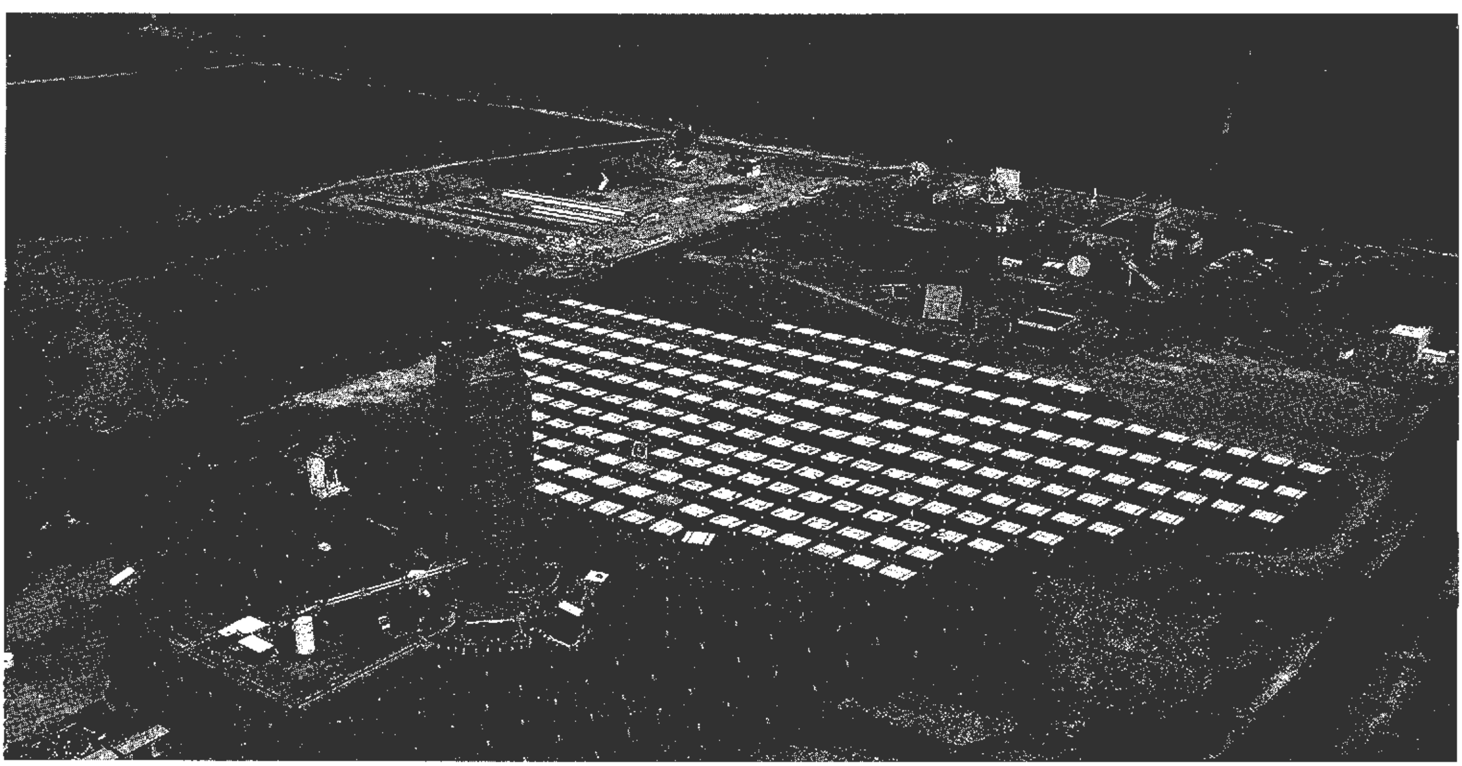
Schematic of Cascaded System

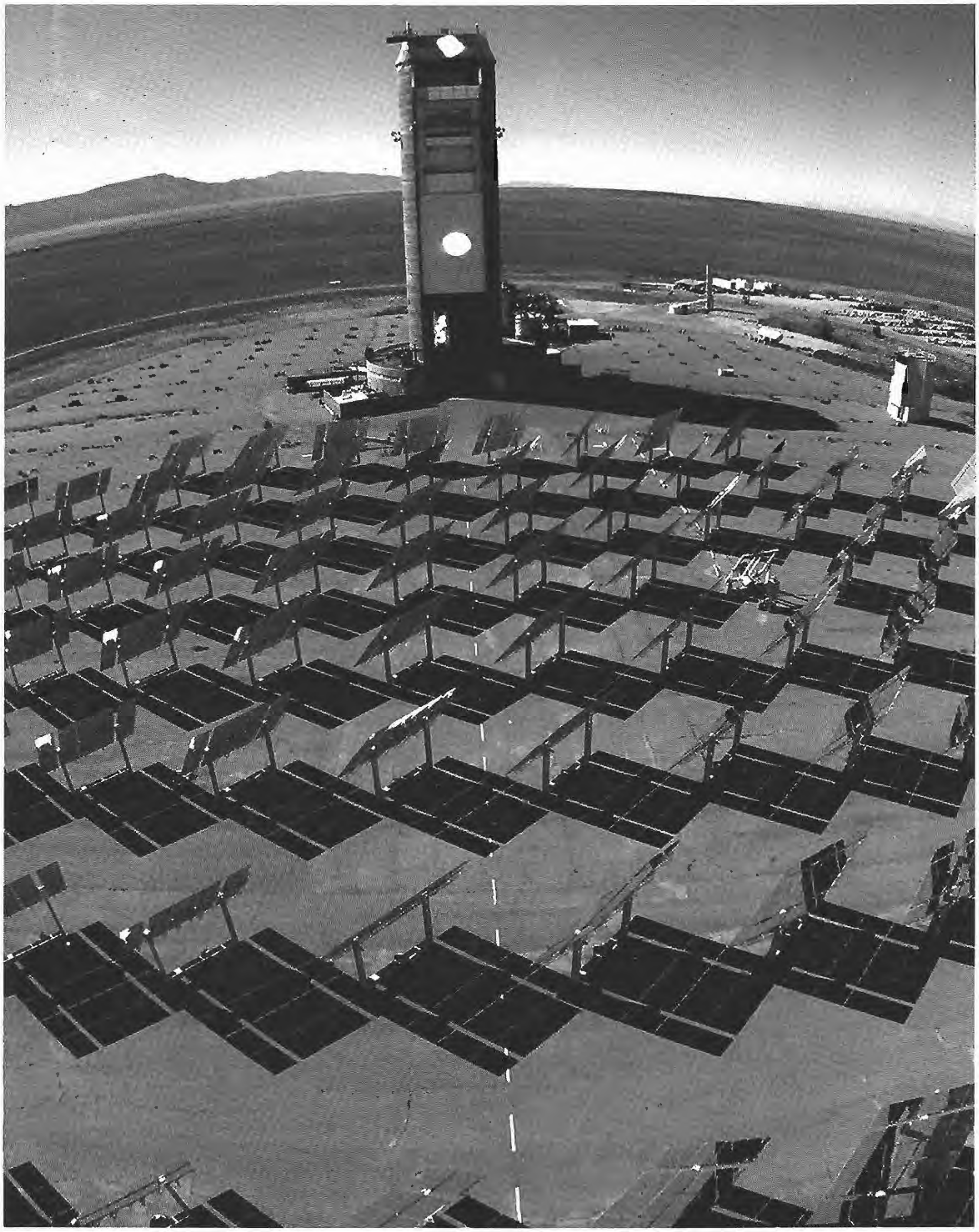
A 1974 schematic illustrates the early "solar total energy" concept for using the sun's heat to provide communities with electricity, heating, and cooling.

John Holmes concluded that much was learned from Solar One, which used a simple water boiler as its receiver to produce steam to drive a turbine-generator. Through research and experimentation, Sandia identified improvements in receivers and heliostats that lowered their costs while increasing their efficiency, and methods for storage of energy to be used at night. Reducing the costs of solar thermal energy into the range of costs associated with fossil and nuclear energy plants became a primary goal for this program, and Holmes asserted that "the technology for the next plant promises to produce electricity competitively."

The distributed receiver concept evolved out of Sandia's work on the solar total energy concept. Solar total energy research began in 1972 with funding from the National Science Foundation. In 1977, Sandia was named technical project manager of the national Solar Total Energy Program. The concept

A variety of distinct test facilities make up the National Solar Thermal Test Facility at Sandia New Mexico. Identifiable here in 1993 are, *far left background,* the Parabolic Trough area; *behind the trough area,* the Engine Test Facility; *left background,* the Distributed Receiver Test Facility; *right background,* the Administration Building with control tower; *white building on far right,* the 16kW Solar Furnace; *foreground,* the Central Test Receiver Facility, known as the Power Tower.



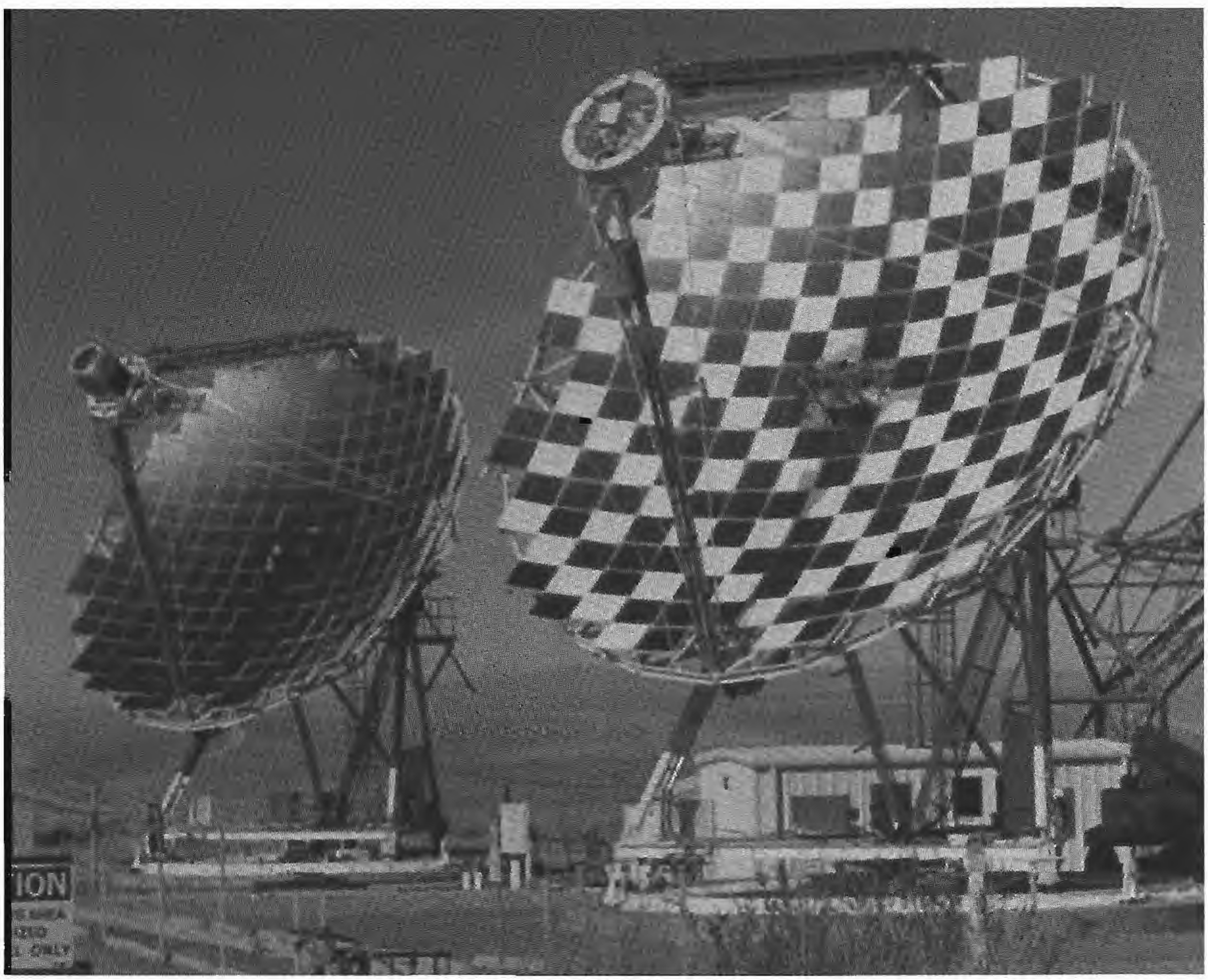


A field of 220 heliostats at the Central Receiver Test Facility focuses sunlight onto the tower. Tests can be conducted at different levels, including the base of the tower.

behind solar total energy was to use solar systems to fill a range of energy needs, wasting as little energy as possible. Sandia's approach was to use high temperature working fluid to generate electricity and then use the low temperature waste heat from electricity generation for space heating, process heating, air conditioning, or other applications. This effort resulted in many technical successes, including a major installation of parabolic dish technologies in a total energy system at a knitwear factory in Shenandoah, Georgia. Good total energy applications were scarce, however, and the program evolved into the distributed receiver project.

In contrast to central receivers, the distributed receiver concept provided a receiver for each reflecting surface, either a reflecting dish or a reflecting trough that concentrated sunlight on the receiver. A receiver could be linked directly to a heat engine, or the heat produced at several receivers could be transported to a single heat engine or to a user of thermal energy. Stromberg, Bob Alvis, Jim Leonard, and associates provided project research and management for early applications of distributed receivers to power pumps for agricultural irrigation. Test projects using solar-powered pumps were completed near Willard, New Mexico, and Coolidge, Arizona, during the late 1970s, but Leonard concluded that "marketplace economics weren't yet there" to support the widespread application of solar irrigation systems. Industrial process heat was a more attractive early market.

As in the central receiver programs, costs became a primary concern in the development of distributed receivers. As Tom Mancini observed, "We're not trying to build



Sandia's test bed concentrators are used for performance testing of Stirling engine and receiver components.

a Ferrari, we want to build a reliable workhorse that is more plain vanilla — maybe a Chevy or VW Bug." As distributed receiver technology matured, Sandia shifted research from parabolic-trough systems to emphasize the dish-Stirling concept. This approach, spearheaded by Rich Diver, linked parabolic-dish reflectors with simple Stirling heat engines to produce stand-alone power at any plant capacity, large or small, with the potential to serve remote geographic areas. According to Leonard, the dish-Stirling system approached an efficiency level rivaling that of diesel-generated power.

THE EGGBEATERS

Solar interactions with the atmosphere produce winds, an energy source used since ancient times for propulsion, milling, and pumping, and more recently to produce electricity. Responding to the 1973 requests for energy research proposals, Randy Maydew, Ben Blackwell, Lou Feltz, and Jack Reed considered how Sandia's aerodynamics experts might contribute to the need for alternative energy sources and hit upon "the eggbeaters" concept. Canadians had begun studies of a device patented in France in 1925 that resembled an eggbeater, rather than the typical propeller-type windmill used to pump water. Properly named the vertical-axis wind turbine (VAWT), it had airfoil blades that provided lift like an aircraft wing and rotated into the wind, regardless of the wind direction.

With initial funding from the National Science Foundation, Maydew and his associates built desktop models, then a larger prototype atop Sandia's Building 802, followed by still larger prototypes. Richard Braasch, Henry Dodd, and colleagues continued this research on improving the aerodynamic efficiency. "We emphasized structural dynamics and how to use aerodynamics to make an inexpensive machine," Braasch reported, adding that controlling the vibration levels of the machine during operation proved a challenge. Using analytical techniques developed in the weapon programs, Sandians

Ben Blackwell, Randy Maydew, and Lou Feltz in 1975 stand before one of the prototype vertical axis wind turbines ("eggbeaters").

achieved fundamental understanding of the loads and turbine responses. "This took a dedicated analytical effort by several Labs organizations," observed Emil Kadlec, project manager of the research team, but "if you can predict these, then you obviously know the variables that control fatigue life and you can alter those variables to enhance fatigue life."

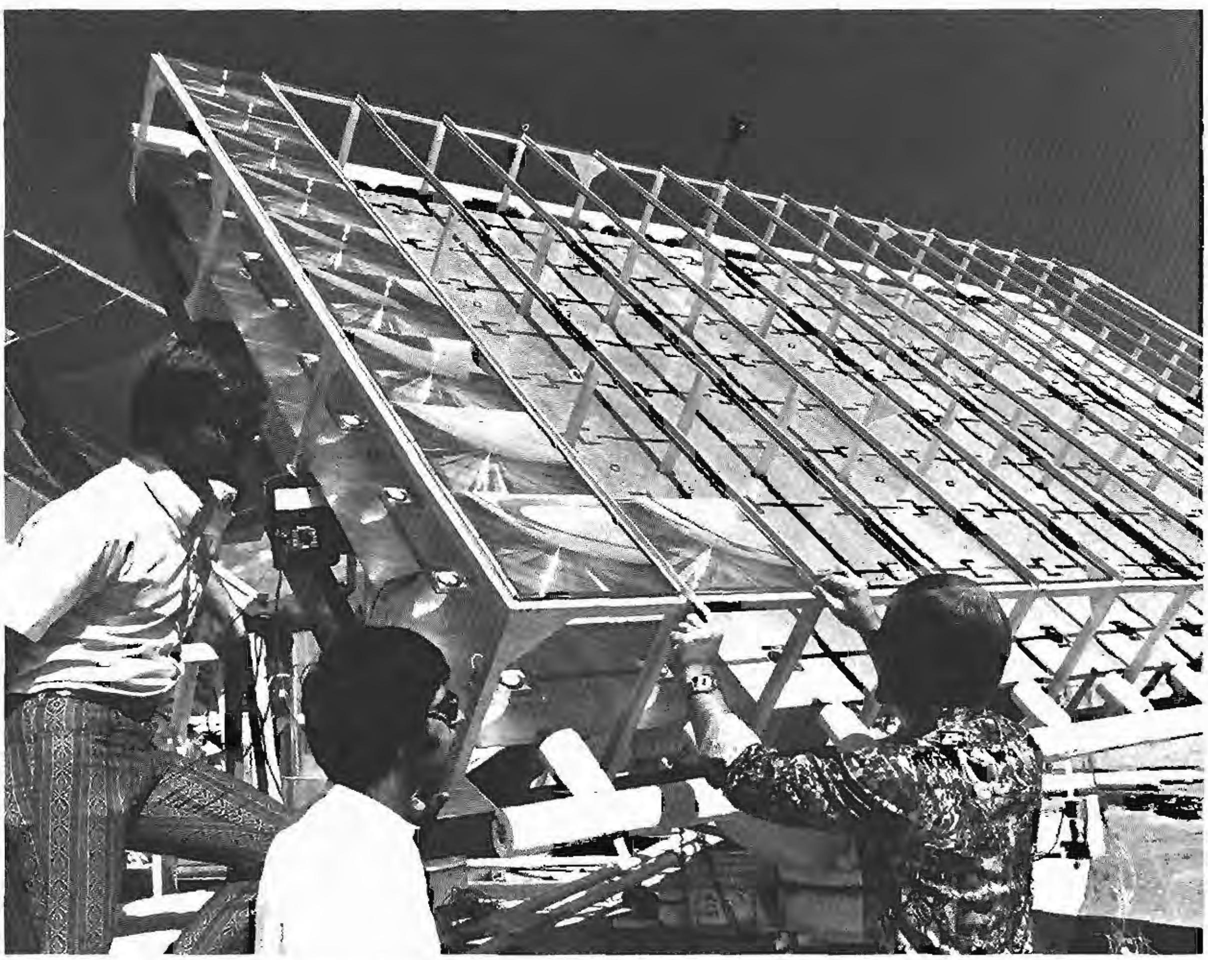
"The Holy Grail of the moment," Paul Klimas declared, "is to reduce the cost of generating energy with wind turbines." Interested in the design of a highly reliable and low-cost wind turbine, industry used Sandia's research to build commercial wind farms in California consisting of over 500 units at Altamont Pass east of Livermore and in the Tehachapi Mountains north of Barstow. Dodd described this as "technology transfer, derived from systems-engineering expertise, followed by successful commercialization in the late 70s." VAWT proved cost-effective so long as oil prices were high, and research continued in later years at a large experimental vertical-axis wind turbine built on the windy Texas plains.

PHOTOVOLTAICS

Developed by Bell Laboratories in 1954, photovoltaic cells — solar cells that convert sunlight directly into electricity — were first used to provide power for satellites, including the VELA satellites of the early 1960s. Made of semiconductor materials that use absorbed light particles (photons) to generate charged particles carrying electric current in the semiconductor, photovoltaics promised a convenient and relatively clean energy source if their efficiency could be increased and their costs reduced.

Photovoltaics was a good match to Sandia's expertise in semiconductor science and technology. Working with ERDA staff at first, and later DOE, George Samara developed plans for a major Sandia involvement in the national photovoltaics program.

To pursue this technology, Sandia formed a photovoltaic group managed by Don Schueler. "It really wasn't a question of whether solar cells would work — the space program had already proved they would work," Schueler observed, "but solar cells were incredibly expensive." Photovoltaic power in 1975 cost $3 per kilowatt-hour, compared to about a dime per kilowatt-hour for fossil fuels, and the long-term research goal of ERDA and Sandia was to bring photovoltaic costs within range of fossil fuel costs.



In 1976, Sandians install Fresnel lenses to focus sunlight on experimental photovoltaic cells. *Left to right:* Gene Hammons, Don Marchi, Ed Burgess.

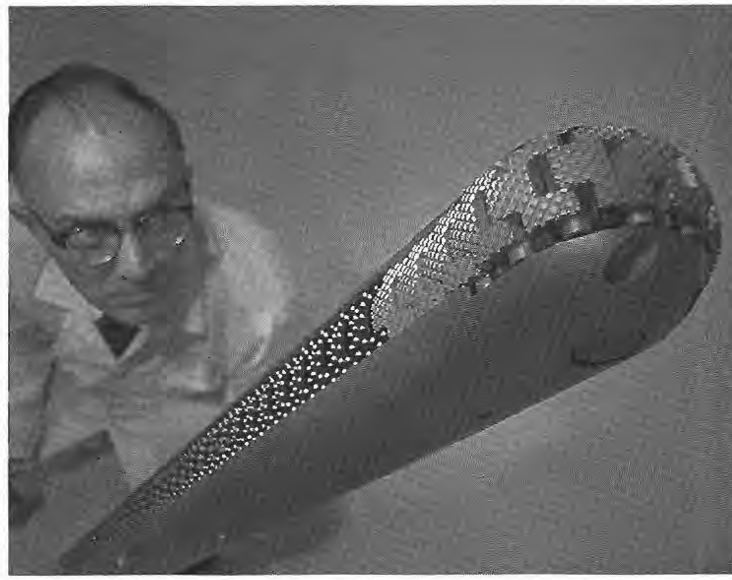
Don Shuster, Congressman Harold Runnels, and Max Newsom in 1974 discuss one of Sandia's drilling tools.

During the first year, Schueler's team designed a photovoltaic concentrating array, using plastic Fresnel lenses to focus sunlight on the cells and a surplus Army searchlight mount to keep the array pointed toward the sun. Several utility companies later copied the design in early attempts to build and operate photovoltaic power systems.

In 1975, ERDA selected Sandia to manage the Systems Definition portion of the National Photovoltaic Conversion program. Responsible for systems definition and analysis as well as developing tracking and concentrator subsystems, Sandia explored a variety of total energy systems. In 1976, Sandia opened a Semiconductor Development Laboratory managed by Bob Gregory that produced experimental solar cells, although its principal function focused on very large integrated circuits. Within months, this laboratory produced solar cells that were eleven-percent efficient, compared to the three-percent efficiency of commercial solar cells then available.

Sandia continued research to improve solar cell efficiency into the 1990s, achieving thirty-one percent efficiency and creating a design assistance center to provide information on photovoltaics advances to the private sector. In addition, there was considerable work on supporting systems such as tracking and control, DC/AC inverters, and flat-plate reliability. Dan Arvizu of Sandia's photovoltaic research division asserted that the efficiencies achieved at Sandia and elsewhere put photovoltaic power in reach of market entry and made it useful for providing electric power to geographic areas remote from utility power grids, especially to villages needing electricity to pump water or refrigerate vaccines.

Wayne Young, John Colp, and Glen Brandvold in 1974 examine their air-dropped penetrator with instrumentation for locating magma energy sources. As part of its geothermal energy investigations, Sandia tested these penetrators in Hawaii and Alaska.



Dick Ashmore displays a model of the continuous chain drill bit developed at Sandia.

GEOTHERMAL DRILLING INITIATIVES

"George and I were considered to be people who thought about the unusual, the strange," said Tony Zuppero, recalling his work with George Barr when brainstorming energy research for Don Shuster. After considering alternatives from tidal power to oil shale, Barr and Zuppero recommended that Sandia study tapping into the subsurface heat of volcanic magma. The geothermal energy of subsurface magma had already been tapped in seismically active parts of the world, notably in Iceland, and Sandia had designed weapons to function in hostile environments, so why not design tools to operate in volcanoes?

Modestly funded by the AEC physical research division, Sandia began its investigations of extracting geothermal energy from magma in 1974 when Harry Hardee reported it was feasible to drill holes several miles deep to reach volcanic magma and to devise the means of applying geothermal heat to steam boilers, thereby spinning turbines to produce electric power.

Sam Varnado inspects one of the diamond-studded drill bits designed by Sandia for use in the petroleum and energy industries.

Mark Davis examined the corrosive effects of molten magma on metal alloys that might be used as heat exchangers. Terry Gerlach and Bill Luth studied volcanic gases and magma to understand the underground environment that might be encountered. John Colp worked with the U.S. Geological Survey, which was evaluating energy resources including magma, and assembled an advisory group of government, industry, and university participants to guide the research. Early experiments included the use of terradynamics and weapon detonators to assess geothermal potential in Alaska. This research led to successful drilling of well bores into subsurface molten rock at 1000° C at Kilauea Iki, Hawaii, followed by successful heat extraction experiments designed by Hardee. Subsequent review of all the program results by a geoscience panel concluded that the tapping of magma bodies was scientifically feasible. The emphasis of the program was then shifted from determining scientific feasibility to evaluating engineering feasibility.

Directly tapping into magma for energy recovery would require drilling miles of boreholes through hard rock, and Don Shuster asked Max Newsom to investigate drilling technology. "I headed an exploratory development group working on theater nuclear weapons," Newsom remembered, "Don Shuster, who foresaw the energy crunch long before it happened in 1973, introduced us to drilling; he considered it a key technology for a number of energy areas."

Having no expertise in drilling, Newsom went directly to the oil industry for help "since we knew if we did anything worthwhile related to drilling, it had to be picked up by industry to have any value." Newsom received excellent cooperation from industry, and he formed an industrial committee for technical review of Sandia's research. "One thing became clear early on," he said, "all our geothermal advances — especially in drilling mechanics — had to have applications in oil and gas activities; otherwise, private industry wouldn't pay much attention."

Drilling constituted a major cost for oil and gas explorations, and Newsom learned that the oil and gas drilling industries still relied on a rotary rock-cutting drill bit invented in 1908 by Howard Hughes, Sr. Because these bits became dull and had to be changed frequently, the drillers had to pull the entire drill stem from the borehole to switch the bit, a slow and costly process in deep drilling. Newsom saw that Sandia could advance drilling technology by designing bits that could drill faster, last longer, and stay down in the boreholes. "We are the unquestioned leader in fireset technology," Newsom declared. "We have built reliable hardware that functioned in more extreme environments than the bottom of an oil well. We have the people and the experience to analyze shock interaction for optimum rock fracturing."

Securing funding from the ERDA geothermal division, Sandia's investigations focused initially on innovative drill bit designs. Taking their cue from Sandia's terradynamics research, Newsom and Bob Alvis invented a "terradrill," in which bullet-like projectiles were fired down through the bit to break the rock ahead of the drill. Bob Fox and Neil Botsford conceived of a chain bit, which could rotate new cutting surfaces onto a bit face without pulling the bit from its borehole. Sandia also investigated the Russian spark drill that used high-voltage electric sparks at the drill head, which created shock waves in the drilling fluid to break the rock.

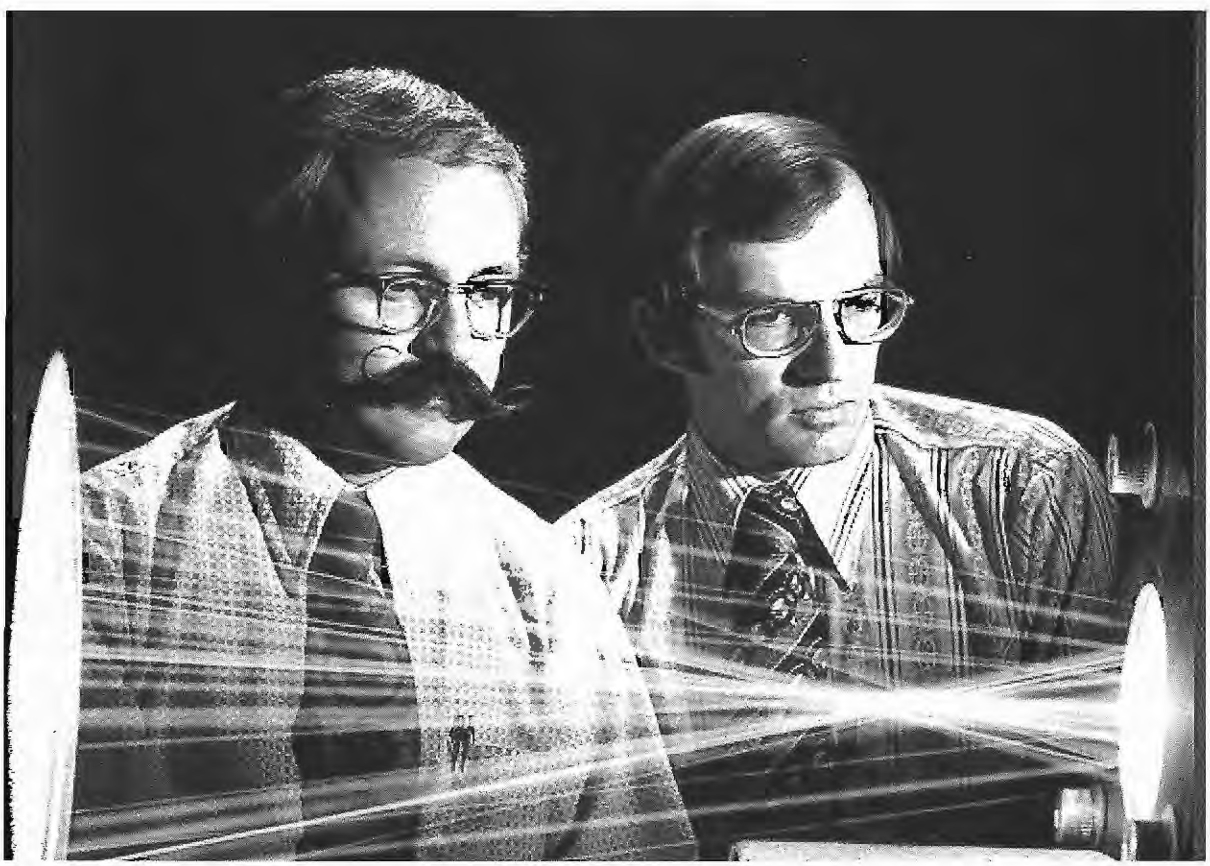
Working closely with drilling companies, Newsom learned that "in the end, economics drives the drill," and the cost of adopting Sandia's more innovative drilling concepts proved too high for the industry. Greater success came from Sandia's improvements to a drag bit with cutters made of synthetic diamond originally developed by General Electric in 1955. "It was clear they had a lot of potential," said Newsom, but the cutters often broke loose from the bits, and Sandia set to identifying the causes and remedies for this defect. Using ultrasonic testing, Ed Hoover and Charles Huff found that the bond between the diamond cutters and the drill head needed improvement, and Jim Jellison proposed diffusion bonding to lock the cutters to the drill head.

Sam Varnado and James Kelsey followed Newsom as leaders of Sandia's drilling research, with David Glowka managing continued research on the synthetic diamond cutters. As Sandia improved the diamond-tipped cutters, private firms marketed them for wide application in the petroleum industry; within a few years, these bits were used for about a third of all oil and gas exploration. As part of its drilling research, Sandia also developed high-temperature drilling fluids and well-logging equipment along with a host of additional innovations that were soon commercialized. Varnado passed along comments from private industry that "without Sandia's technical contributions these bits and their impact on reducing drilling costs would never have been realized."

A survey by Virgil Dugan and Dick Traeger indicated that more than forty of Sandia's drilling technology advances were adopted by industry, and the Sandia drilling group had became a recruiting source for the petroleum industry. The survey noted as well that the technology transfer to industry had been accompanied by technology transfer back to Sandia's weapon programs. Out of drilling technology research came quartz tuning forks for use as timers, high-temperature diodes for service in radiation-hardened circuits, borehole navigation systems useful in missile guidance, and aqueous foams that could help protect storage sites. Both the industrial and weapon applications of drilling technology made it a shining example for technology transfer advocates, perhaps second historically at Sandia in immediate applications only to the Whitfield clean room.

TURBULENT FIRE

Another area of significant technology transfer at Sandia was combustion research — fundamental investigations of combustion engines and furnaces based on the gas-dynamic diagnostic and computational capabilities developed for weapon gas transfer systems. Its origins trace to research by Dan Hartley and Ron Hill during the early 1970s on using lasers to investigate turbulent gas flow — information useful in the design of boost gas reservoirs. With mirrors, they



Ron Hill and Dan Hartley in 1973 display their light-trapping system for intensifying laser beams.

Morgan Sparks, Sandia president, meets President Gerald Ford in 1975.

bounced laser light back and forth through a gas sample, then analyzed the light by Raman spectroscopy, a technique used to identify the chemical species within a gas. By examining the color of laser light after it passed through a flame, Hartley and Hill could determine what kind of molecules constituted the flame and thereby gain insights into combustion processes.

Because combustion in engines and furnaces is the principal power-generating mechanism for most industrial, commercial, and transportation processes, and is a major pollution source, Arlyn Blackwell and Dan Hartley in 1973 examined the potential contributions of laser combustion diagnostics to national energy research needs. They prepared a proposal, sent it to Washington, and in 1974 received modest funding to initiate combustion research. A Princeton summer study that year reviewed the ways physics, meaning measurement, diagnostics, and rational analysis, might contribute to an understanding of combustion and concluded that a much larger program would be required.

In 1975, when Tom Cook suggested that Sandia propose a national center for combustion research, Hartley and Blackwell drew up a proposal for a combustion research facility (CRF) at Sandia California. Don Hardesty and Peter Witze were soon joined by Bill McLean, Jim Miller, Reginald Mitchell, Larry Rahn, and other experts on combustion processes. This team contributed design innovations for diesel engines, pulse combustors for furnaces, and pollution reduction methods. "Since the days of the energy crisis," Hartley declared, "the CRF team has helped to convert science and technology into energy security."

The solar power tower and related research facilities at Albuquerque and the CRF in California became Sandia's first "user facilities." Located outside fenced and classified weapon development areas, these facilities welcomed research participation by representatives from industry and universities. The CRF, for example, often conducted work in tandem with corporate researchers from General Motors, Ford,

Gamma Ray Astronomy

The nature of the center of our galaxy is a prime mystery in astronomy. Located in the constellation Sagittarius, it cannot be seen by ordinary telescopes because dust clouds in the Milky Way block light from the galaxy's core. Developing detectors for gamma-rays, or high energy photons, in 1975, Sandia and Bell Laboratories opened a new window into the galaxy's center.

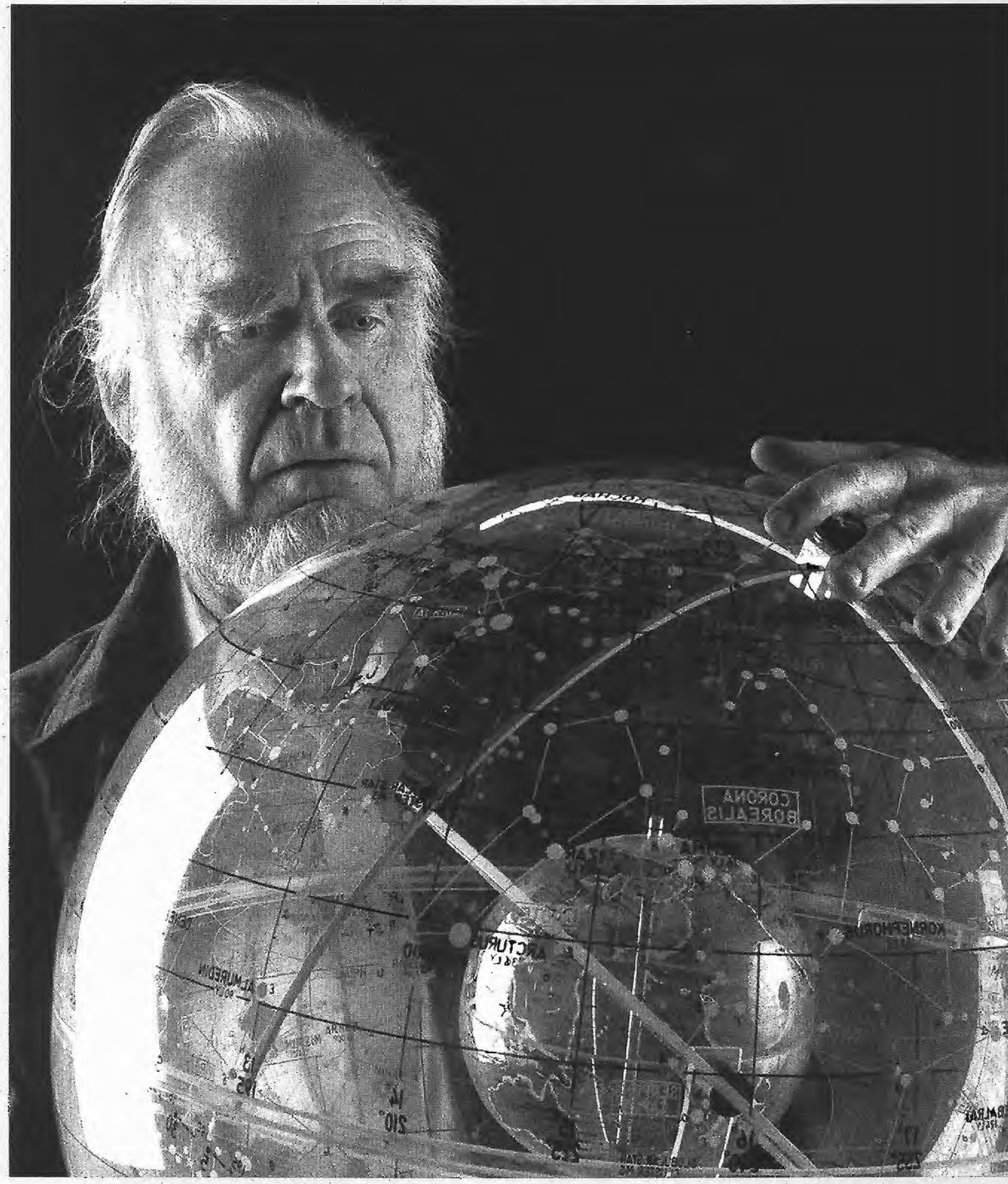
Seldom can the origin of a science be so closely pinpointed as that of gamma-ray astronomy. It began near dawn on May 10, 1976, near Alamogordo, New Mexico, when a Sandia balloon hoisted skyward a gamma-ray detector package designed by Sandia and Bell Laboratories. Marvin Leventhal of Bell conceived of using large germanium crystals to measure gamma-ray energies and sending these crystal detectors aboard balloons above the atmosphere to reduce gamma-ray attenuation. Crawford MacCallum, Al Watts, Paul Stang, and a Sandia team designed a gamma-ray telescope to aim the crystals at the stars, collect the data, and return it to earth, along with huge polyethylene balloons to carry the package 25 miles above ground. They hoped to obtain data on nucleosynthesis, the creation of heavy elements in the stars, and thereby learn something of the formation of the universe.

The 1976 flight focused on the Crab Nebula and other supernovas, beginning the systematic analysis of gamma radiation from space. Also observed was a gamma-ray spike coming from the vicinity of the galactic center, and in 1977 Sandia and Bell Laboratories launched another balloon package at Alice Springs, Australia, specifically to measure gamma-ray energies from the galactic source. Crawford MacCallum was amazed by the intense gamma-rays coming at a specific energy from the galactic core. These data suggested the existence of some exotic object. Others speculated on the nature of this object, postulating that it might be a "black hole" emitting gamma rays when it annihilated electrons.

In 1979, a Jet Propulsion Laboratories' satellite equipped with a gamma-ray detector confirmed what Sandia's balloon flight had observed, but in 1980 the satellite could not find the gamma-ray spike again. Sandia launched another balloon package in Australia in 1981 and learned also that the gamma-ray emissions had ceased. This ruled out several speculations on the source of the gamma rays, and MacCallum said, "The only thing that could turn off that quickly is a black hole."

Sandia joined Bell Laboratories and the Goddard Space Flight Center in seeking funding for the design of more sensitive gamma-ray telescopes and for satellites to carry them into space. In 1988 they sent their new Gamma Ray Imaging Spectrometer (GRIS) up via balloon to examine a new supernova, and, to their surprise, they learned that the gamma-ray energy spike from the galaxy's center had returned. A 1989 University of California balloon observation, however, saw that the spike had turned off. Astrophysicists asserted the erratic waxing and waning of the gamma rays perhaps resulted from changes in the rate at which matter was drawn into a black hole. When matter entered a black hole and its electrons were annihilated, it emitted gamma rays; a hiatus in the flow of matter ended the gamma-ray emissions until more matter arrived.

Although the nature of the galactic center is far from resolved, Sandians and gamma-ray astronomers have continuing interest in this mystery. Even after retiring, Sandia's "astronomer by appointment," Crawford MacCallum, maintained a professional role in the investigations.



Retired Sandia physicist Crawford MacCallum normally studies the universe from the other direction, looking out instead of in. In 1990 he assisted NASA's Goddard Space Flight Center with the launch of a balloon-borne gamma ray observatory.

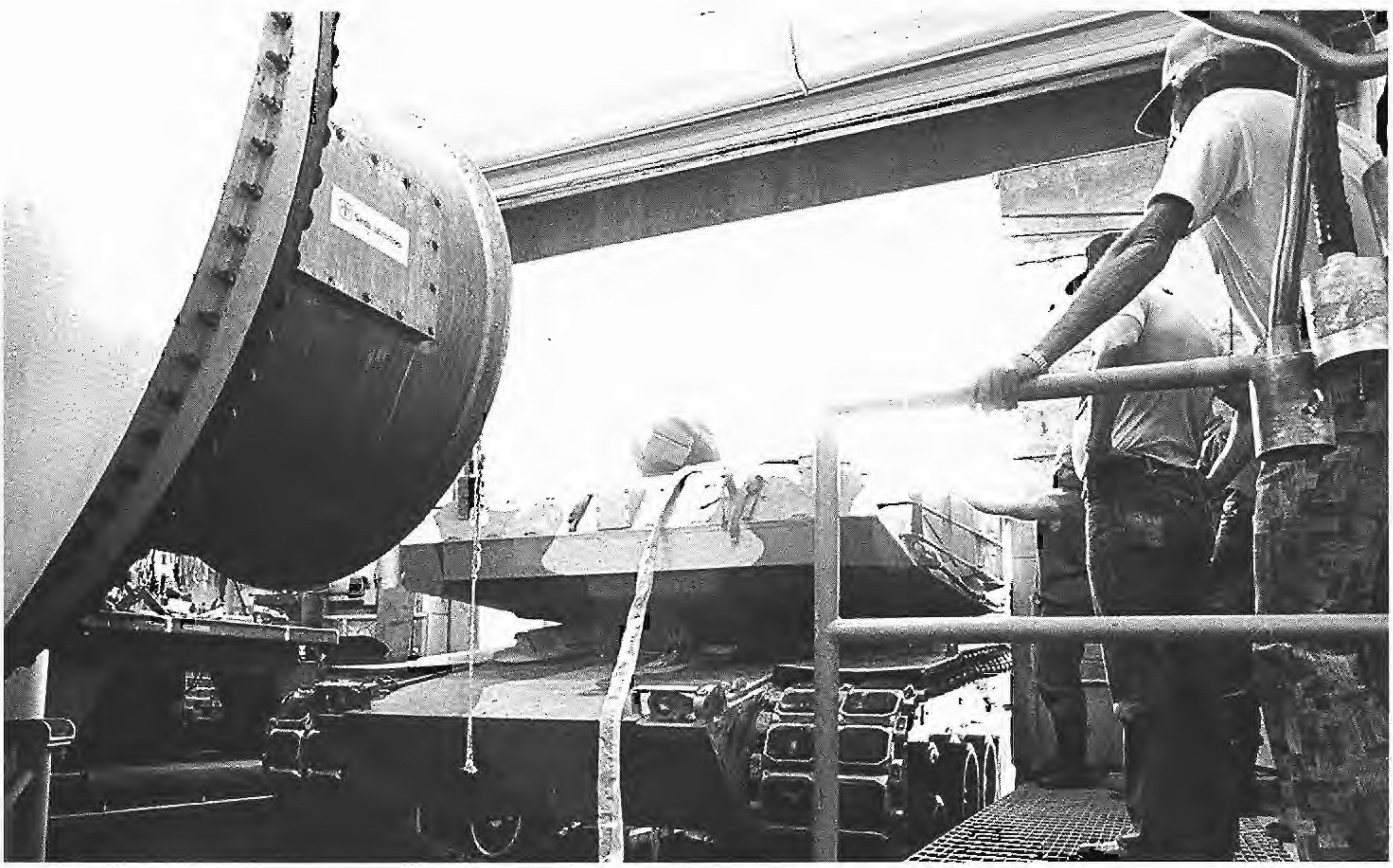
Cummins Engine, and Lennox Industries and provided opportunities for university post-graduate research.

FUSION AND PULSED POWER

More directly than its other energy programs, fusion research emanated from Sandia's weapon programs. For simulation of weapon effects on materials and components, the AEC military applications division during the 1960s funded the development of large machines like SPASTIC and Hermes. Bill Snyder initiated the Sandia effort in the development of a large machine to generate pulses of gamma rays and electrons. Ken Haynes, Tom Martin, and Ken Prestwich managed and designed these early machines with the able assistance of Charlie Martin and Ian Smith of the British Atomic Weapons Research Establishment. The machines used banks of large capacitors charged in parallel to release a short duration, high-voltage pulse of power that tested the ability of weapons components to withstand gamma radiation.

Jack Walker and his staff began to adapt these machines to explore extracting the electron beam directly from the REBA and HYDRA machines, and focusing it on materials to simulate the x-ray effects. This initiated Sandia research on beam-plasma interactions.

When Gerold Yonas joined Sandia in 1972, he and Prestwich conducted intense beam-pinching experiments on the Sandia low-impedance mylar-insulated accelerator. Yonas recognized that directing such a self-pinched, focused electron beam onto a pellet of deuterium-tritium could be a competitor to pulsed laser beams for initiating a



Sandia's pulsed power research began with simulations of effects on weapons. In this 1979 photograph, Sandians prepare to test the effects of gamma rays on an armored vehicle by using the Hermes II accelerator (barrel-like structure in the upper left-hand corner).

controlled thermonuclear (fusion) reaction through inertial confinement.

Efforts to achieve a reaction releasing fusion energy began in the United States in 1951 as Project Sherwood. Under AEC management, it became a large and well-funded program because it promised an abundant and relatively clean energy source. Deuterium, a hydrogen isotope, is found naturally in seawater, while tritium, another hydrogen isotope, can be made in a nuclear fission or fusion reactor from plentiful lithium. If these isotopes could be fused, the oceans could become an almost inexhaustible energy source. "If we can do it," one official proclaimed, "that's the foundation for a civilization."

Early fusion research at Los Alamos, Oak Ridge, and other laboratories concentrated on magnetic fusion by using huge magnets to confine cloud-like plasmas of deuterium within metal containers that often had the toroidal shape of a doughnut. The main problem was to maintain the plasma in a stable configuration long enough for fusion to occur. Since inertial confinement fusion requires a considerably shorter confinement time, Yonas proposed in 1973 that Sandia join in studies of this new approach using electron beams.

Inertial confinement fusion relies on the fuel's inertia (the tendency of matter to resist changes in its motion) to maintain a compressed state long enough for a fusion reaction to occur. When fired at fuel pellets the size of a BB, electron or photon beams drive or compress the pellet inward, creating an extremely hot and dense core where a fusion reaction might occur.

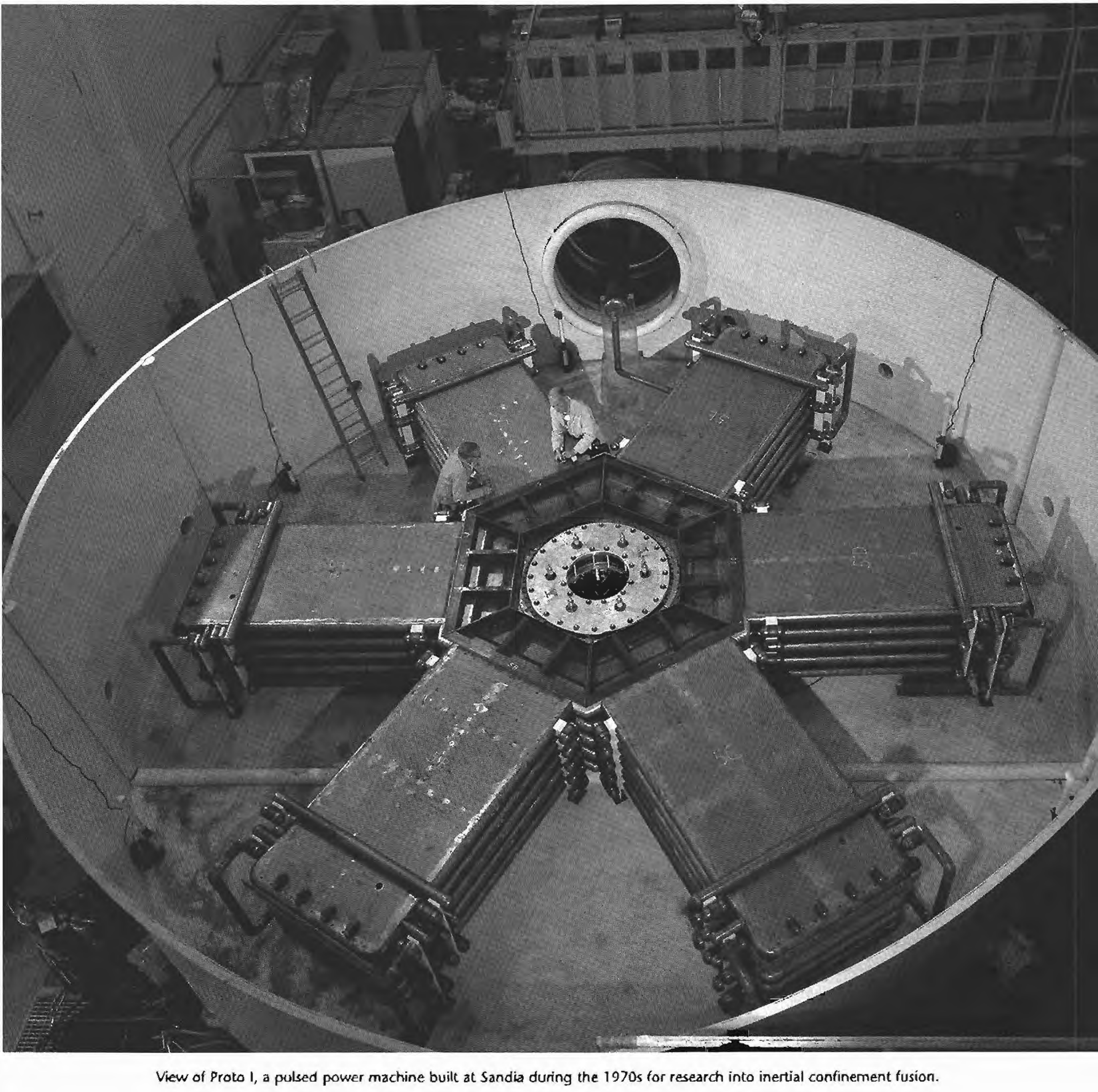
To achieve a controlled reaction producing fusion energy, several conditions must be met. The nuclei of the fuel (deuterium and tritium) must speed toward each other fast enough to overcome the repulsive electrostatic forces. Thus, the fuel's temperature must reach about 100 million degrees, and the fuel must hold together long enough for the nuclei to collide and fuse.

In 1973, the AEC fusion research division first funded Sandia's efforts to overcome the formidable challenges required for fusion energy. Yonas noted that Sandia's proposal received a boost from the 1973 announcement by the Soviet Kurchatov Institute that it intended to pursue fusion through use of electron beams. Over the following years experiments and collaborations with the Soviets continued to be important.

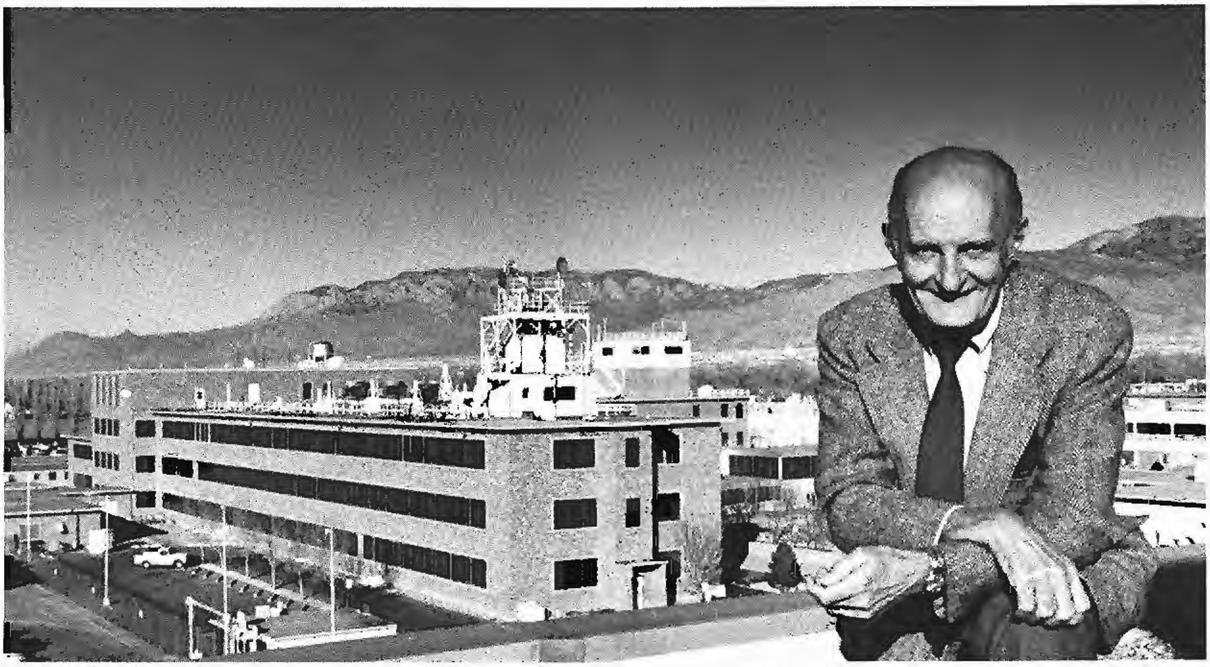
Initially, Sandia's research emphasized the physics of electron beam focusing and energy absorption in solids. "A major problem," Yonas said, "is that of coordination — to combine the scientific, engineering, and systems approaches optimally." Leading the studies were John Freeman's plasma theory group, Al Toepfer's electron beam staff, and Tom Martin's pulsed power group. Early work also included a four-beam laser developed by Eric Jones and Jim Gerardo for both weapons effects simulation and fusion research — the first U.S. system that could focus more than two beams on a target pellet. In 1975, Robert Gerber, Edward Patterson, and associates designed a new hydrogen-fluoride laser, the most energetic pulse laser then existing. However, Yonas shifted the emphasis from lasers to electron beams to take advantage of Sandia's unique capabilities in pulsed power.

The first Sandia accelerators designed specifically for fusion research were Proto I (Prototype), which began operation in 1974, and Proto II (1977). However, when Sandia proposed the Electron Beam Fusion Accelerator (EBFA), obtaining the funding proved difficult until in 1976 the Soviet scientist Leonid I. Rudakov revealed that the Kurchatov Institute had used electron beams to create fusion neutrons. Yonas credits Senator Joseph Montoya with pushing the EBFA funding through Congress with strong support from Al Narath and Morgan Sparks.

While EBFA was under construction, it became apparent that ions, rather than electrons, would be more effective in coupling energy into targets, and Martin managed the conversion of the EBFA into the Particle Beam Fusion Accelerator (PBFA). Despite this change, Martin pointed out



View of Proto I, a pulsed power machine built at Sandia during the 1970s for research into inertial confinement fusion.



Morgan Sparks, Sandia's president, 1972-1981, stands on the roof of Building 803 with Sandia Crest in the background. Building 800, *left*, is Sandia New Mexico's main public entrance.

that Sandia, by project fast tracking, thanks mainly to project leader Gerald Barr and assembly chief Johann Seamen, completed the first PBFA on budget and on time — two days ahead of schedule on a four-year long project.

By the late 1970s, it appeared that Soviet scientists were developing beam weapons, and Sandia joined the Air Force Weapons Laboratory in studies of a particle beam machine named RADLAC, implemented by Ken Prestwich, which might become the basis of a beam weapon. Therefore, directed energy was added to simulation and fusion as a component of the pulsed power program. This was one of Sandia's entries into a field that later became the Strategic Defense Initiative, or Star Wars, during the 1980s.

By the late 1970s, Sandia had achieved recognition as a world pulsed power leader, and its program proceeded on three research fronts: weapons effects simulation, particle beam weapons, and fusion energy. "Sometime in the next century," Yonas predicted, "we may have pulsed power playing an important role as the energy source of the future."

THE MULTIPROGRAM LABORATORY

By 1976, energy and reimbursable programs had grown to approximately a quarter of Sandia's annual budget. Its budget for 1976 totaled $280 million: $209 million for ERDA defense programs, $21 million for ERDA energy programs, and $50 million for reimbursables funded by other agencies, chiefly the Nuclear Regulatory Commission and Defense agencies.

Staffing for these non-weapon programs came largely from the exploratory and advanced technology fields hit hardest by the declining weapons budget. In many cases, the new energy and reimbursable programs allowed Sandia to keep a nucleus of experts active in critical technologies that would not have been possible with weapon funding alone. "New initiatives in non-weapons work are exciting, and I believe they are vital to the future of Sandia, but in focusing attention and publicity in these new areas we should not lose our perspective," Morgan Sparks warned. "Most of our people still support our historical functions — functions that the nation will continue to need in the years to come."

Sandia's accomplishments in its historical functions during the early 1970s included completion of a revolutionary integrated, miniaturized, and radiation-hardened arming, fuzing, and firing design for the Poseidon missile warhead and radiation-hardened designs for the Sprint and Spartan warheads of the Safeguard system. In view of the constrained budgets, Sandia tailored weapons for specific operational scenarios by using the B61 bomb design as the building block for depth bombs, Pershing missiles, and for such exploratory programs as the TIGER extended-range bomb. Through studies such as Allspice and Jigsaw, Sandia emphasized maneuverability and precision with increasingly accurate guidance and control.

With the end of the Vietnam war and growing concern about Soviet weapons expansion, Congress augmented ERDA defense programs funding. Announcing Sandia's first significant hiring program in years, Sparks declared in 1976: "We all know that money is much tighter than in the '60s, but then we've learned these last few years how to manage under this constraint. I think we've come a long way since the dark days of the layoffs — just consider the diversity of our efforts. And while weapons are the mainstream activity, Sandia has succeeded in staking out a significant portion of the energy business."

There were Sandians, however, who thought the distinction drawn between defense and energy programs too sharp. Virgil Dugan, for example, argued that energy programs enhanced "the nation's security by making it more self-sufficient and less dependent on foreign energy sources." No nation could long survive without adequate energy sources, he pointed out, nor could motorized armed forces function without energy supplies. "An army marches on its stomach," said Napoleon, but modern armies must have gasoline and oil.

In its new solar, wind, photovoltaic, geothermal, combustion, and drilling technology ventures, Sandia learned that its reputation rested not entirely on innovative technology, but on technology that industry could apply quickly at prices competitive with older technology. "It has become clear that the fundamental consideration in the energy field is economic," Sparks summarized. "Our principal job is to so design these systems that the energy produced is less — or at least no more — expensive than that available from conventional sources."

Giving primary consideration to economics marked a significant transition in the thinking of Sandia's engineers. In 1952 at Sandia, during the urgent weapons development era, Bob Peurifoy observed that "cost was of little consequence." During the leaner 1960s, Monk Schwartz and John Hornbeck devoted close attention to cost control and case system management; but during the retrenchment of the early 1970s Sparks and his staff lived with the tightest constraints. Cost became a significant consideration in weapon development, but reliability and safety always had higher priority. It was in the early energy programs, however, that Sandians faced up to the informal professional definition: "An engineer is a person who can build for one dollar what anyone can build for ten."

An important lesson drawn from Sandia's energy initiatives — early involvement of industry in development processes — became important to research and design and to technology transfer. Sandians institutionalized this lesson in their energy programs, and ERDA further encouraged close contacts with industries by naming Sandia as the center for technical administration of industrial research contracts in such fields as solar thermal and photovoltaic energy.

Adding energy research and safety assessment to Sandia's traditional defense programs, ERDA in 1975 named Sandia as one of eight "multiprogram laboratories."

MORTGAGES, LOANS, AND SHEEP

Kirtland Air Force Base branch of the Sandia Laboratory Federal Credit Union as it appeared in 1996.

The Sandia Credit Union

Sandia Laboratory Federal Credit Union was federally chartered in October 1948 when 15 employees of what was then Sandia Laboratory, a separate branch of Los Alamos Laboratory, saw the need for a credit union in postwar Albuquerque. Housing and financial services were in short supply near the base, which was growing in relative isolation miles to the east of the city's business district. The Credit Union's name still reflects the early Lab's title, with the singular "Laboratory" and lacking the later adjective "National."

The Credit Union was, and still is, a cooperative — member-owned and operated. The charter members and the directors they elected were very close to the day-to-day running of the Credit Union, approving new members and individual loans — functions now largely handled by a professional staff. But today's Credit Union is still overseen by an active, involved Board of Directors made up of elected members who volunteer their time and talent without pay.

The charter members began that first month with $535.75 in total assets, operating the Credit Union from a cash drawer in a wooden barracks building on Sandia Base. In winter, wind-driven snow infiltrated the walls. By the Credit Union's first anniversary, assets had climbed to $11,765.87 with $9,445.35 out in loans and a serious delinquency rate of almost 12%. (A collection note from the early 1950s referred to recoverable property in the form of sheep located on the East Mesa.) The difficulty was transitory, however, and delinquencies were greatly reduced over the next two years

By the mid-1950s, the Credit Union had grown sufficiently to support hiring an outside professional manager. David Tarbox, the Credit Union's elected president, recalled being asked by one of the candidates: "How much do you expect the Credit Union to grow?" Assets were at almost $1 million in 1955, and Tarbox predicted that $10 million in assets was probably not unreasonable at some time in the future. That mark was passed in August 1967. The books closed on 1995 with $388.4 million in assets, making the Credit Union Albuquerque's largest locally owned financial institution. Members originated 7,125 loans totaling $263.4 million in 1995 — the delinquency rate was a minuscule 0.3%.

On October 31, 1969, ground-breaking was held for the current facility at Wyoming Boulevard and J Street on Kirtland AFB. An office at Sandia/California in Livermore opened in 1975 and was serving some 4,500 members in 1995. In 1988 a Credit Union Center opened in the far Northeast Heights of Albuquerque because over 70% of Credit Union members lived within two miles of that facility. Plans were being formulated to open a West Side Albuquerque branch (on the west bank of the Rio Grande) in early 1997.

The test launch of a Minuteman missile, seen left of the cloud, from its circular silo produced a smoke ring visible above the cloud.

VI

THE NATIONAL LABORATORIES

Since World War II, while we have not had peace, neither have we had the prophesied nuclear war. And some people think the reason the large nations, the world powers, haven't gone to war, is because of the reality of the great destructive threat posed by nuclear weapons.

Morgan Sparks

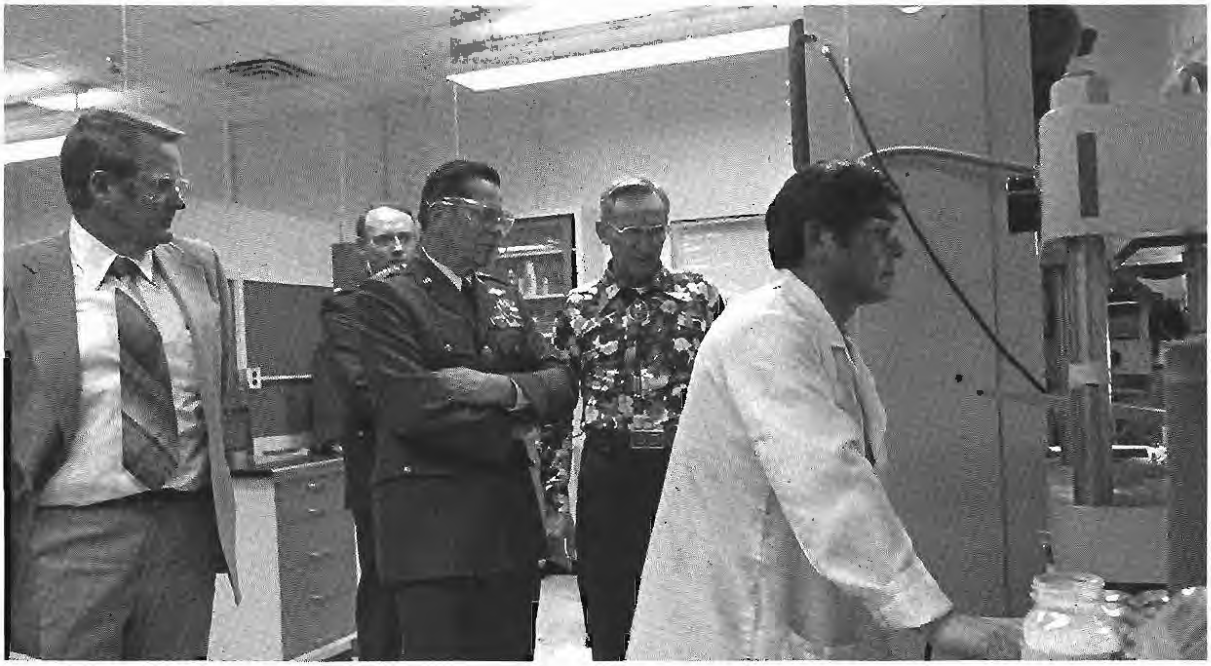
Sandia's weapon programs entered a new phase during the late 1970s, dominated by safety and use control improvements as well as schedule and performance. Sandia designed warhead subsystems for Minuteman, Poseidon, and Pershing missiles, for new types of cruise missiles, for nuclear artillery shells, and for strategic bombs. The demands of these projects returned Sandia's staffing to pre-1970 levels.

As proposed by Presidents Gerald Ford and Jimmy Carter, Congress created the Department of Energy (DOE) in 1977, consolidating the Energy Research and Development Administration, the Federal Energy Administration, and the Federal Power Commission in a single cabinet-level agency. This top-level transition had few immediate effects on Sandia's programs, although its energy and environment programs moved in new directions. In addition to continuing its weapon, verification, and energy programs, Sandia expanded into new areas of technical research. It explored subsurface coal gasification and oil shale energy resources; it advanced deep drilling and downhole steam technology; it searched beneath the seas and the earth's crust for suitable sites to isolate nuclear wastes and store petroleum reserves; and it continued studies of penetrator weapons that could get at deeply buried and hardened targets.

As the 1970s closed, Sandia's involvement in international arms control and test ban negotiations increased because its advancing sensor technology contributed toward assurance that treaty violations would not go undetected. Although the Soviet invasion of Afghanistan and the Iranian revolution and oil embargo disrupted international affairs and test-ban negotiations in 1979, Sandia's verification research suffered no hiatus. During the disruptions of that year, Congress designated Sandia and its partners, Los Alamos and Lawrence Livermore laboratories, as Department of Energy National Laboratories, responsible for many programs in addition to their traditional weapons tasks.

DEPARTMENT OF ENERGY CREATED

In January 1977, during one of the coldest winters of the century, President Carter declared the energy emergency to be the "moral equivalent of war." On his desk in the Oval Office, Carter found President Gerald Ford's recommendation for the creation of a Cabinet-level Department of Energy. Carter accepted this proposal and Congress approved it in August 1977, establishing a Department of Energy (DOE) that inherited the Energy Research and



Robert Peurifoy, General Robert Dixon, and Bob Wehrle in 1977 observed the work of Geronimo Fragua in Sandia's thermal battery laboratory.

Development Administration's facilities, including Sandia. Congress dispensed with its Joint Committee on Atomic Energy as well, transferring its role in authorizing nuclear weapons programs to the House and Senate Armed Services committees. President Carter named James Schlesinger, the former AEC chairman and Secretary of Defense, the first Secretary of Energy.

Some Sandians worried about this change. Reassuring them, Morgan Sparks said, "We are a proven, mission-oriented engineering lab — really a scarce resource that is much needed for national purposes." Tom Cook observed that even the accounting and budgeting systems remained intact, and the transition from ERDA to DOE proved easier than the earlier switch from AEC to ERDA.

After the formation of DOE, another study of transferring nuclear weapon programs to the Department of Defense began, managed by General Starbird. Completed in 1980, the Starbird study recommended continuing the dual agency program, with DOE and DoD having shared and joint responsibilities. Gene Ives of Sandia contended that this dual agency policy had resulted in advances by DOE and its predecessors in the face of disinterest elsewhere. "A few such advances that come to mind," Ives recalled, "are the submarine-launched ballistic missile program and the MIRV program in general; the PAL program in particular and the improved security/command and control program in general; and the improved safety design for abnormal environments as spawned by our independent safety conscience."

PRECISE INSTRUMENTS

"Emphasis today is not on weapons with bigger effects, but rather on safer ones that are even less likely to experience an unintended detonation," said Sparks, reflecting on the nuclear weapon programs of the late 1970s. "Most of today's weapons are less powerful but more precise instruments designed for use against military targets."

During the 1970s, nuclear weapon programs experienced a resurgence. According to General Edward Giller of ERDA, this came in response to aggressive Soviet weapon programs that erased most of the

Sandia engineers Jim Lindell, Howard "Tom" Lehman, and Charlie Burks pose in 1978 with one of their modifications of the multipurpose B61 bomb.

U.S. quantitative lead in strategic weaponry between 1965 and 1975. Giller declared that the determination of the U.S. to maintain technological superiority was reflected in its 1977 defense budget, which included real increases in spending for the first time in years. At Sandia, Sparks announced this increase as a reversal of "the long erosion of our capabilities." By 1976, five nuclear weapons had entered phase 3 development: an improved warhead for the Trident missile (W76), an eight-inch nuclear-tipped artillery shell (W79), a warhead for the Minuteman III missile (W78), and two bombs, the B77 and an enhanced version of the older B61.

During the 1970s, Sandia received a reimbursable assignment from the Navy to design an integrated arming, fuzing, and firing system for Trident I, the follow-on to the Poseidon missile. (The mythical god Poseidon carried a three-tined spear called a Trident, and the Navy used this image to represent its new submarine, missile, and refitting facilities). Bob Christopher, Sam Jeffers, and Ben Bader coordinated design of Sandia's arming, fuzing, and firing assembly for the Mark 4 reentry body (with its W76 warhead), the payload for the Trident missile, with the Navy and with Lockheed, the missile contractor. According to Herman Mauney of Sandia's team, working with Lockheed and the Navy on this project proved to be a "real pleasure."

Sandia's design for the Mark 4 arming and fuzing system included a radar fuze and an electronic timer. The radar was the result of an advanced development program headed by Charlie Blaine of the radar advanced development division. The goal of this program was to develop a fuze of superior performance, weighing less than one and one-half pounds, and occupying about 25 cubic inches, less than half that of the Poseidon radar. Blaine named the new fuze "lazo," which in Spanish means shoestring.

A Trident II missile breaks the water after a submarine launch.

Above: Sherry White was one of the ceramists who formulated the composition of high-field varistors in 1978 that could control voltages ten times higher than low field varistors. The new type she holds in her left hand could do the same job as the longer type in her right hand.

Above: Bill Clement displays Sandia's PAL controller designed in 1976. In his right hand is a custom-made large scale integrated circuit, and in his left hand are six of the circuits mounted on a thick-film interconnect board. These components were first used in the PAL controller.

Ray Alls in 1978 discusses the Mark 4 "lazo" radar fuze with George Rodgers.

A W79 is shown in flight at an Army test ground near Yuma, Arizona in 1980.

The name, he felt, was in keeping with his development budget. The radar design included radiation-hardened, beam-leaded, small-scale integrated circuits, and thin-film hybrid microcircuits, technologies adapted in part from previous work at Bell Laboratories.

The phase 3 development program on the Mark 4 radar was directed by George Rodgers and Ray Alls, with major contributions from Charles Williams, Bob O'Nan, and Don Arquette. Prototype and production units were supplied by Bendix Kansas City in an effort headed by Don Peterson and Tom Wiley. The program resulted in the smallest, lightest, best-performing, and most reliable radar that Sandia or anyone else ever designed. Rodgers liked to say, "It has never failed and it never will."

Among its other distinctions, the Trident reentry body design became the first Sandia weapon project to enjoy regular audits by the General Accounting Office. Sandia completed the design for the Trident I at costs slightly less than forecast in 1973, and Bader announced Sandia's pride, "because we believe we've succeeded in holding to our basic philosophy — to develop a weapon with an acceptable level of reliability at a reasonable cost." First production of the weapon came in 1978, and the Navy deployed it on Trident submarine missiles during the 1980s.

Design of an eight-inch nuclear artillery shell, designated the W79, for Army theater defense began in late 1975, with Don Bohrer managing Sandia's project group and G. A. "Ben" Benedetti and Mel Callabresi analyzing the structural design. As the first nuclear shell designed to be similar ballistically to the conventional shell (to ensure maximum accuracy), the W79 presented severe design challenges.

In 1976, Clarence Loveless and Max Schell designed a telemetry package that could withstand the shock of firing from an artillery piece.

For structural analysis of the W79, Benedetti and Callabresi developed computerized models to aid the design process. "Designing is an iterative process," explained Callabresi. "It's cut and try. In the old days, cut and try meant committing a design at a certain stage to hardware, then testing it and going back to the drawing board. With our model, it's possible to test a given design on paper, saving a lot of dollars."

Although use of computer modeling reduced the number of developmental tests needed, field tests remained necessary to validate the computer models, and testing an artillery shell subject to as much as 12,000 times the earth's gravitational acceleration during firing presented stiff challenges. When testing earlier artillery shells, Sandia had mounted data recorders outside the gun barrel and run a wire down the barrel to the shell; they collected data until the shell left the barrel and broke the wire. But under a 12,000 G stress, such wires broke immediately. Given the task of designing telemetry for the shell, Clarence Loveless and Max Schell adopted a frequency-stabilized transistor for the telemetry that would stay on frequency even during the shocks of firing, and, moreover, they developed a reusable package. "It all hangs together in that gun barrel," noted Loveless, declaring that the telemetry packages were used in thirty or more firing tests. With this and

Shipboard test launch of a Tomahawk cruise missile.

other advances, Sandia completed its designs and the W79 entered production in 1981.

By 1976, cruise missile technology had advanced far beyond that used in the earlier Matador and Regulus missiles. Lightweight and efficient propulsion engines with on-board computers for navigation guidance and terrain-following radar for target recognition and altitude control allowed the new class of cruise missiles to follow convoluted low-altitude courses and approach targets from almost any direction. To reduce the costs of arming cruise missiles, DOE reported that one warhead could be developed to fit several configurations of the new missiles.

Morgan Sparks announced in 1976 that Sandia would design systems for a single warhead, the W80, for application to three cruise missiles — the Navy Tomahawk, the Air Force subsonic missile to be launched from B-52 aircraft, and the Air Force supersonic missile, named Short Range Attack Missile (SRAM-B), launched from the B-1 bomber (this missile program was later canceled when the B-1A bomber was canceled). "The W80 is a complex system that offers significant challenge," Sparks admitted, adding, "This is major work to which we will devote our best efforts."

Paul Longmire managed Sandia's development of the W80, with Dick Jorgensen leading the electrical design and Curt Moses and Don Spatz sharing mechanical design responsibilities. John Duncan initially managed the W80 tests with cruise missiles that could circle for hours before hitting targets, presenting interesting test requirements. A test of an inert Tomahawk missile, for example, involved a launch off the coast of California, a flight inland to Sandia's Tonopah Test Range in Nevada, then loitering above the range for hours before slamming into the target.

A similar program begun in 1979 involved design for the W84 warhead to be used in Tomahawk cruise missiles modified for tactical use by the Air Force. Arnie Rivenes managed Sandia's design of the W84 arming and firing components, structural parts, and permissive action link, with Bill Pontsler and Carl Furnberg serving as lead engineers. In addition to the Trident and

In 1977, Bob Gattis of Los Alamos observes as Gene Ives shows the Trident arming, fuzing, and firing system to Air Force Secretary Thomas Reed and Morgan Sparks.

Tomahawk missile programs, Sandia also worked closely with the Navy in designing systems for the W81 warhead. This was to arm the Aegis missile for defending ships against missiles that could sink carriers even with a near miss. For this design, Garry Brown and Sandia's systems studies group developed computer models to evaluate warhead design requirements. "Our close working arrangement with the Navy on this tactical weapon," Brown observed, "should lead to a better understanding of their requirements for tactical nuclear weapons."

When engineering development for the W81 began in 1977, Ben Bader became the project engineer with Gene Ives as program manager. Because the W81 was for ship defense against missiles, Sandia selected the older Sprint antiballistic missile warhead (W65) as the basis for the W81 design. Concerns about the arms control implications of this missile suspended the project in 1978, but the Navy resumed the studies in 1979. Ives and Bill Nickell led Sandia's team during the redesign, developing a new kind of fireset and an integral strong link. As requirements changed, this project extended into the 1980s under Heinz Schmitt's management before new defense priorities resulted in its cancellation.

In 1979, Jim Barham, Don Bohrer, and Joe Vieira inspect the eight-inch artillery shell designed with a nuclear punch.

During the late 1970s under a strict budget imposed by Congress, Sandia began developing the W82 design for artillery shells that could be fired by the 155-millimeter howitzer by the Army and NATO forces. Don Bohrer and Bill Wilson managed this project for Sandia with Dennis Beyer and Jack Martinell as the lead engineers for the design of the structural case as well as the arming and firing components. "The biggest challenges are to pack a sophisticated weapon inside a round only about six inches across and to protect it from the severe gun loads ... as the round is fired from a

Four members of the Sandia project team display parts of the B83 in front of a test casing. *Left to right:* Mike Neuman, Rex Eastin, Rodger Page, Jim Dremalas.

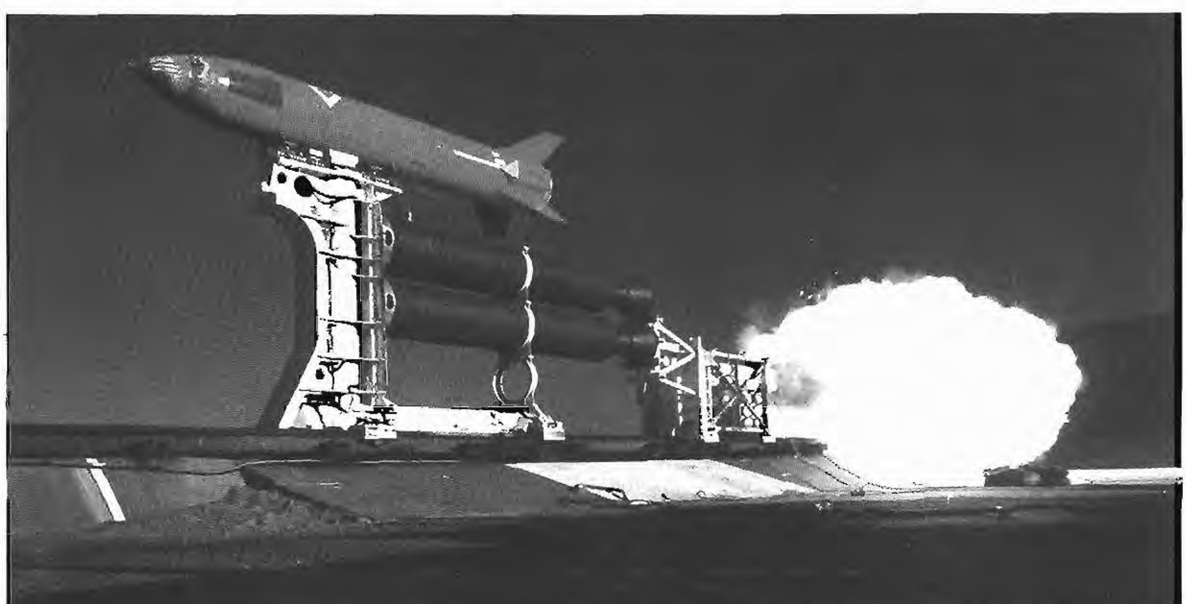
howitzer's rifled barrel," declared Bohrer. "And it has to have the same ballistic characteristics as a conventional round. Finally, it has to meet strict budgetary requirements." Sandia's earlier experiences in the design of the W79 eight-inch round proved useful in designing the W82 and helped to contain development costs.

Summing up Sandia's weapon programs of the 1970s, weapons development director Bill Spencer explained: "We proceed on three assumptions. First, nuclear weapons remain the keystone to national defense. Second, because resources to develop them are limited, there is a need placed on us for the highest order of engineering skill. And third, to be a credible deterrent our nuclear weapons must be modern yet cost-effective."

Cost concerns in 1977 caused DOE to suspend Sandia's development of the strategic, high-yield B77, which incorporated new safety features and several design innovations. On the advice of the Office of Management and Budget, President Carter scrubbed the expensive B77 project in late 1977 in favor of modifying the existing B43 bomb developed in 1957-58. After reviewing the economics of this decision, the House Armed Services Committee concluded that any savings from modifying the existing B43 were illusory, and it refused to fund the modifications. Sandia continued the studies of the B77, found ways to reduce development costs, and in 1979 received approval to resume strategic bomb development on the system, which had been redesignated B83.

Jim Wright, Cliff Potthoff, Gary Beeler, Duncan Tanner, and Arnie Rivenes led project teams that added several novel design improvements to the B83. They used custom-made, large-scale integrated circuits the size of postage stamps to make the B83 a "thinking" bomb. It had a computer-controlled parachute system and a roll-control system to impart spin for ballistic stability. It was specifically designed to be laid down on hard and irregular targets such as railroad yards, and it had a unique shock-mitigating nose that reduced impact stress on the bomb's internal parts. Together with a new solid-state fuze, new trajectory sensors, and new thermal batteries, the B83 design represented a technical achievement of the first order.

With the B83 design, Sandia entered a new weapon program phase, dominated not only by schedule and performance but also



A rocket-propelled test of a B83 test unit on the Sandia sled track. The first-stage Zuni rockets fired first, as seen in this picture, followed by the larger Nike rockets beneath the unit.

B83 program managers Jack Wirth, Gary Beeler, and Jim Wright visited the Bendix plant in 1979 to check component manufacture.

by cost-effectiveness, by improved command and control, and by improved safety and use control. To achieve cost reductions, Sandia used components and technologies developed for the B61 and B77. "We're constantly scrubbing material costs with Don Shuster and Dick Claassen, component costs with Don Gregson, Charles Tapp and Gene Reed's 2000 organization, test costs with Roger Baroody and Bill Gardner," noted Jack Wirth of the B83 team, "and we're concerned with the costs of the whole bomb system, from its inception through production and stockpile sampling." Development of the B83 continued into the 1980s, and it entered the stockpile in 1983.

On the other hand, Congress in 1981 canceled development of the W86 nuclear penetrator weapon for the Pershing II missile system. Sandia had been selected by the Army in 1975 to develop the earth penetrator arming and fuzing and penetrator case along with Sandia's traditional area of responsibility for the warhead electrical system and flight test telemetry. This project was conducted in close coordination with the Army office at Redstone Arsenal, which had responsibility for Pershing II missile development, and Martin Marietta, Orlando, the Army missile system prime contractor. Fired from a mobile launcher, the three-stage missile and associated reentry vehicle carried the earth penetrator to an impact point on, or above, the target. At target impact, the earth penetrator separated from the reentry vehicle and penetrated deep into the target before detonating. The resulting underground detonation was designed to produce larger craters and target kill radii with smaller yield on targets such as aircraft runways and underground structures.

Ray Reynolds, Heinz Schmitt, Bill Alzheimer, Don McCoy, Bill Patterson, and Sam Jeffers were among the Sandians managing the engineering challenges posed by the W86 Pershing II penetrator warhead program. One challenge involved ensuring survival of the penetrator case and functioning of the arming, fuzing, warhead electrical system and nuclear device during the severe shocks and high deceleration

In 1980, Heinz Schmitt displays three different views of the Pershing II penetrator tested by Sandia. He is holding a telemetry battery pack.

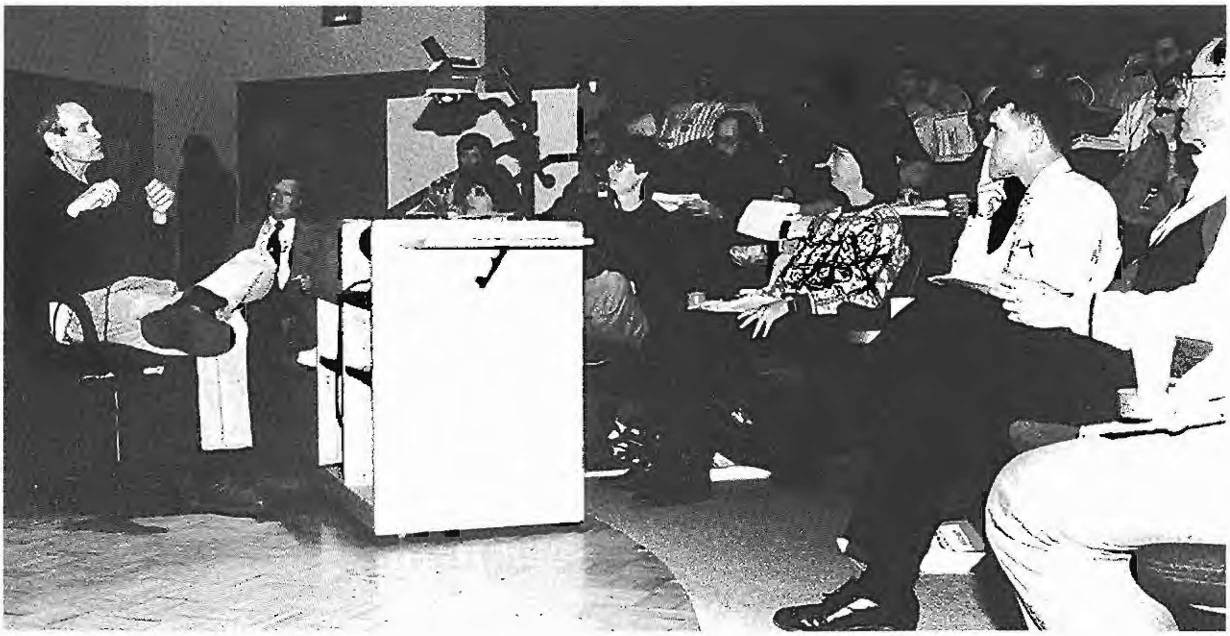
forces associated with earth penetration. The firing command, which resulted in the firing set initiating the nuclear device detonators and initiating the neutron generators, was generated during penetration by a depth-of-burial fuze.

Another challenge involved the test and evaluation program: characterization of penetrator case, internal structures, and internal functional hardware; and the recovery of penetrators deeply buried below the surface of the ground. Pershing II penetration tests included sled track tests, Davis gun tests at the Tonopah Test and White Sands Missile Ranges, and full missile system flights into White Sands Missile Range. Davis gun tests were fired into soil and rock targets while the missile tests went into soil targets layered with rock. After each penetration test, large-scale mining and excavation operations were conducted to locate and recover the penetrators in order to retrieve on-board telemetry data and to postmortem the hardware. The program successfully demonstrated that technology would support providing a nuclear earth penetrator for delivery by a missile system; however, the Pershing II penetrator warhead was never produced for stockpile use.

Gene Harty displays a prototype Pershing II earth penetrator unit recovered from 33 meters beneath the surface at White Sands Missile Range.

Sandia also continued modifications to the versatile B61 tactical bomb. During the 1970s, modifications 3, 4, and 5 were designed nearly simultaneously, adding nuclear safety features such as lightning-arrestor connectors, insensitive high explosive, weak-link/strong-link exclusion region safety systems, together with improved thermal batteries, parachutes, neutron generators, permissive action links, and other components. Heinz Schmitt, and later Tom Workman, managed design of additional modifications to the B61, and Charlie Burks and Don McCoy subsequently managed the seventh modification, retrofitting earlier modifications with improved design safety and operational flexibility.

Sandia's modifications of the B61 came largely as a result of the stockpile modernization program. As Sandia developed enhanced nuclear safety features, it became apparent that the safety of older weapons might not be sufficient during operational missions. In November 1974 Glenn Fowler had recommended to General Ernest Graves of ERDA's Office of Military Applications that a ten-year joint ERDA-DoD program to improve the nuclear safety associated with air-delivered weapons be initiated. Specifically, it was recommended that seven weapon types either be retired or retrofitted with a weak-link/strong-link/exclusion region safety subsystem and that four weapon types be replaced by new ones already scheduled for production that contained the improved safety features. Until these or similar actions could be taken, Sandia recommended that ERDA recommend to the Secretary of Defense that quick-reaction-alert operations be restricted to missions "absolutely required for national security reasons."



Seated at left, Dick Brodie taught nuclear weapons classes, such as this one, for more than a decade at Sandia.

Fowler's letter, known in some DoD circles as the "Halloween letter," led to the most comprehensive review of nuclear weapon safety to date in a multi-year study chartered in May of 1975. In 1977 Richard Brodie, who had recently retired from the Air Force to become Bob Peurifoy's executive staff assistant, reviewed the 1975 ERDA-DoD safety study as well as other DoD safety and use control evaluations and developed a plan for a Stockpile Improvement Program to address the identified safety and use control issues with a time-phased series of retirements, retrofits, and replacements.

An additional nuclear weapon safety concern arose in the early 1970s around the issue of plutonium dispersal in weapon accidents. Although this concern had been acknowledged and studied since the Plumbbob and Roller Coaster tests of the late 1950s and early 1960s, attention was refocused on the issue in the wake of the debate over U.S. deployment of plutonium-bearing antiballistic missile systems around major cities. Bob Luna led an effort by John Taylor and Norm Grandjean under Bill Stevens' sponsorship to evaluate quantitatively the consequences of plutonium dispersal from potential weapon accidents, which eventually led to a substantially improved understanding of the phenomenology of plutonium dispersal in a variety of weapon accident scenarios. In time, the DOE would add a new safety standard, which mandated positive measures to minimize the risk of plutonium dispersal in accidents, to the four extant standards promulgated by the DoD in 1960.

As funding permitted, the stockpile modernization program continued into the 1990s. Sandia added such features as enhanced electrical safety systems, advanced permissive action links, and command disablement capabilities together with the insensitive high explosives designed at its partner laboratories, to the national stockpile.

FORWARD LOOK

Among Sandia's pivotal studies of the late 1970s was Forward Look, an examination of the safety, security, and survivability of nuclear weapons deployed in NATO countries. This study was managed by Andy Lieber of Sandia's exploratory systems group. The Department of Defense, through Don Cotter of the Military Liaison Committee, requested this study and, with important support from General Joseph Bratton of the ERDA military applications division, Sandia began the work. Don Shuster explained: "We've been asked to look at nuclear weapons deployments for the next 10 years. To do that, we're studying the opposition, matching their plans and capabilities against our own strengths and weaknesses. And we're cranking in other potential problems — terrorists, dissident groups and potential political changes and their implications in foreign governments."

Forward Look concentrated on safeguarding deployed weapons. From these studies came shipping containers to protect artillery shells against fires and flexible armored blankets to protect weapons against small-arms fire. The Defense Nuclear Agency funded full development of the armored blankets, and during the 1990s several thousand were produced and given to Russia to protect the weapons it sent to dismantlement centers.

Recruiting "blackhat" teams to find ways to defeat security and steal weapons, a Forward Look group led by John Kane and Jim Dossey concentrated on access delay and denial techniques at weapon storage sites. It devised an igloo access denial system for improved weapon storage in above-ground bunkers that the armed services renamed the Weapon Access Denial System when they adopted it.

From the Forward Look initiative, the Air Force adopted as well the weapons storage vaults developed and promoted by Kane, Dossey, and Lieber to permit loading weapons inside aircraft shelters. Before Sandia designed this vault, weapons taken from storage igloos were convoyed to the airfields for loading, an operation detectable from a distance, even by satellites. With weapon vaults installed in the floors of hardened aircraft shelters, the weapons could be raised from the vaults and loaded aboard aircraft inside the shelters quickly, making them safe from detection and/or attack by opposing forces.

Lieber, assisted by Bill Roherty, Jim Dossey, and their staff, completed the

Andy Lieber displays copies of the 1979 Forward Look report.

Charlie Daniel and Bill Benedick examine an explosive capsule designed to permit a field commander to destroy a nuclear weapon when in danger of losing it to terrorists or assaulting forces.

Forward Look Study in 1979. In addition to the fielded hardware items such as storage vaults, shipping containers, and armored blankets that were analyzed and recommended by Forward Look, the twenty-nine volume study provided a number of firsts in terms of a comprehensive assessment of safety, security, and survivability. Forward Look provided the first comprehensive assessment of the vulnerability of NATO peacetime storage sites to surprise attack by Warsaw Pact forces. It also included the first comprehensive surveys of weapon storage sites worldwide, covering a wide variety of site types within the Army, Navy, and Air Force. A number of volumes were dedicated to a comprehensive safety and security study of DoD nuclear weapon transportation worldwide. The first assessment of the vulnerability of nuclear weapon high explosives to small arms fire was included. For all the vulnerabilities identified in the site surveys, survivability assessments, and transportation analysis, prioritized potential improvements were identified with cost estimates. For those items that promised the most potential for addressing critical vulnerabilities, such as armored blankets and storage vaults, early prototypes were designed and tested as a concluding phase of the Forward Look study.

COMPUTER REVOLUTION

The Forward Look study, many volumes in length, took advantage of Sandia's new word-processing capability adopted, as it was throughout government, during the 1970s. Although seemingly mundane, the switch from typewriters and carbon paper to computers, printers, and copiers marked a major departure in Sandia's routine. "Before, we had to type and retype to correct mistakes or make changes," said Rosalie Crawford, secretary to Sandia's presidents for thirty-seven years, "whereas now we can just put it on the machine and change it just like that."

Marie Syme, Robert Vokes, Don Emrick, and colleagues studied word processing applications for Sandia in 1976, and, because

Sandia's scientific computing center in 1979 filled with magnetic tapes. Lee Hollingsworth and Kelly Montoya watch Ruth Jones at the console debug a program. In the background are computer operators Fil Tenorio and Mary Couch.

In the word processing center in 1978, Doris Spohr and Jo Chavez use the new terminals and equipment that revolutionized routine paperwork at Sandia.

Rosalie Crawford was secretary to nine Sandia Corporation presidents, beginning with George Landry in 1949. She retired in 1986.

word processing systems then cost up to $20,000 per station, adopted a clustered text-processing center to handle Sandia's word processing. Within a few years, however, low-cost systems were ubiquitous throughout Sandia.

In addition to computer word processing, Jack Howard, Heinz Schmitt, Gino Carli, and associates promoted computer-aided design (CAD) and computer-aided manufacturing (CAM) for producing engineering design drawings. These systems gradually supplanted drafting boards and pen and ink, just as pocket calculators had replaced sliderules. Moreover, once Sandia and the integrated contractors adopted common computer and software systems, design drawings and specifications could be sent electronically from Sandia directly to Kansas City and elsewhere.

"Sandia's product is primarily paper," Bob Henderson once remarked, "in that we produce the drawings, specifications, and other manufacturing information used in getting the weapons built, inspected, accepted and stockpiled." The switch to word processing and computer-aided design therefore marked a significant transition in Sandia's routine.

The 1976 Committee of Secretaries meets with Bob Edelman, Director of Personnel. Left to right: Alice Hodyke, Jo Ann Oswalt, Helen Walsh, Esther Perea, Jan Robertson, June Rugh. The Committee started with six members in 1974 and grew to 18 by 1993.

Secretaries

Like most organizations, Sandia is dependent on capable, efficient secretaries for its smooth operation. Over the years, Sandia and its secretaries have tried a variety of programs to ensure adequate professional development for secretaries and consistent, proficient support for the engineering and scientific activities of the Labs.

Sandia's secretarial staff is managed by Secretarial Services, rather than the managers of the departments to which the secretaries are assigned. Initially, this arrangement allowed for consistency in training and strict oversight of performance, as well as the flexibility to move secretaries into particular departments during sudden increases in work load. Section supervisors were responsible for groups of secretaries, checking on everything from their performance to their appearance. Over the years, this close management has eased, with Secretarial Services serving as the initial training point for newly hired secretaries and as mediator should the secretary encounter problems in the department to which she or he is assigned.

From the beginning, classes have been offered to update skills in mathematical and scientific symbols, handling classified material, and basic secretarial requirements like typing and shorthand. As the job has changed, so have the skills required — shorthand, for example, is no longer a required skill. Marcie Samuelson, who started at Sandia in 1949, noted the change. "When I first came to Sandia, I brought my principal tool with me — an Easterbrook fountain pen. Sandia provided the rest: a manual typewriter and a bottle of Skrip ink." In 1988, she was using an IBM PC and a LaserJet printer.

Computer skills are now a necessity, while stenography has fallen out of use; the training offered over the years reflects these changes. Other skills seem constant. Courses in the 1950s and early 1960s included sections on getting cooperation from others. This element appears in more recent years as part of social styles training, but the emphasis is still on being able to work with a variety of personality types and work styles. In addition to courses offered and required by Sandia, secretaries also took advantage of courses in the community. In 1965, for example, the University of New Mexico offered a business administration seminar for professional secretaries that was advertised in the *Lab News*. Local chapters of the National Secretaries Association (NSA) also organized

In 1989, secretarial supervisors Carol Kaemper, left, and Shirley Dean, right, plan recruiting strategies with employment coordinator Soila Brewer.

workshops and conferences. Sandia secretaries were encouraged to attend and often took an active role in the leadership of the NSA.

One of the avenues of professional development open to secretaries is the study and testing to become a Certified Professional Secretary (CPS). Administered by the Institute for Certifying Secretaries, a department of Professional Secretaries International, the CPS exam covers a vast array of material in subject areas ranging from behavioral science in business, through economics and management, to business law and office technology. Sandia has at times offered tuition reimbursement for secretaries studying for the CPS.

In 1972, Robert Edelman, Director of Personnel, formed the Committee of Secretaries to advise him on matters concerning secretaries without union representation. Made up of Director's secretaries, the Committee served as a sounding board for secretaries, focusing both on issues directly related to the work environment — from testing different typewriter ribbons to suggesting that secretaries be assigned directly to the organization where they worked rather than to a secretarial supervisor — and allowing for professional advancement by arranging management approval for secretaries to attend workshops, conferences, and seminars.

The Committee quickly outgrew its original assignment of advising the Personnel Director, attaining an independence that allowed it to address a wider range of needs through effective communication with Sandia's management. It expanded its membership and became involved in recruiting, sending representatives to area high schools and inviting high school business teachers into the Labs to learn what is required of a Sandia secretary. Stressing the importance of education, the Committee encouraged secretaries to take out-of-hours classes and established an annual seminar, which, by 1987, was large enough to be moved to an off-site hotel. Because of the essential role secretaries play, the annual seminar's sessions have to be repeated because not all secretaries are allowed to attend at the same time since their absence would be too disruptive to Labs operations.

In 1993, the Committee changed its name to the Secretarial Quality Process Council (SQPC) to reflect an increased focus on including secretaries in decisions that affect their jobs. The Council has since gotten more involved in Labs-level decision-making, maintaining strong connections with process management teams and committees.

More significant was Sandia's advance toward the forefront of scientific computing during the late 1970s. "The requirements put on us by new weapon systems got beyond our ability to simply cut metal and try it," explained Ron Detry. The classical methods of attacking design challenges became too difficult or took too long, and the solution was "computer simulations to obtain fundamental understanding of the physics of the process, the mechanics of the process, and also to cut down the time."

Although Sandia had historically used the highest-performance computers available, by the mid-1970s it lagged behind the physics laboratories in computing capabilities, occasionally using second-hand computers from those laboratories. This gap closed as Sandia acquired Crays and other supercomputers to handle increasingly complex scientific and engineering design challenges.

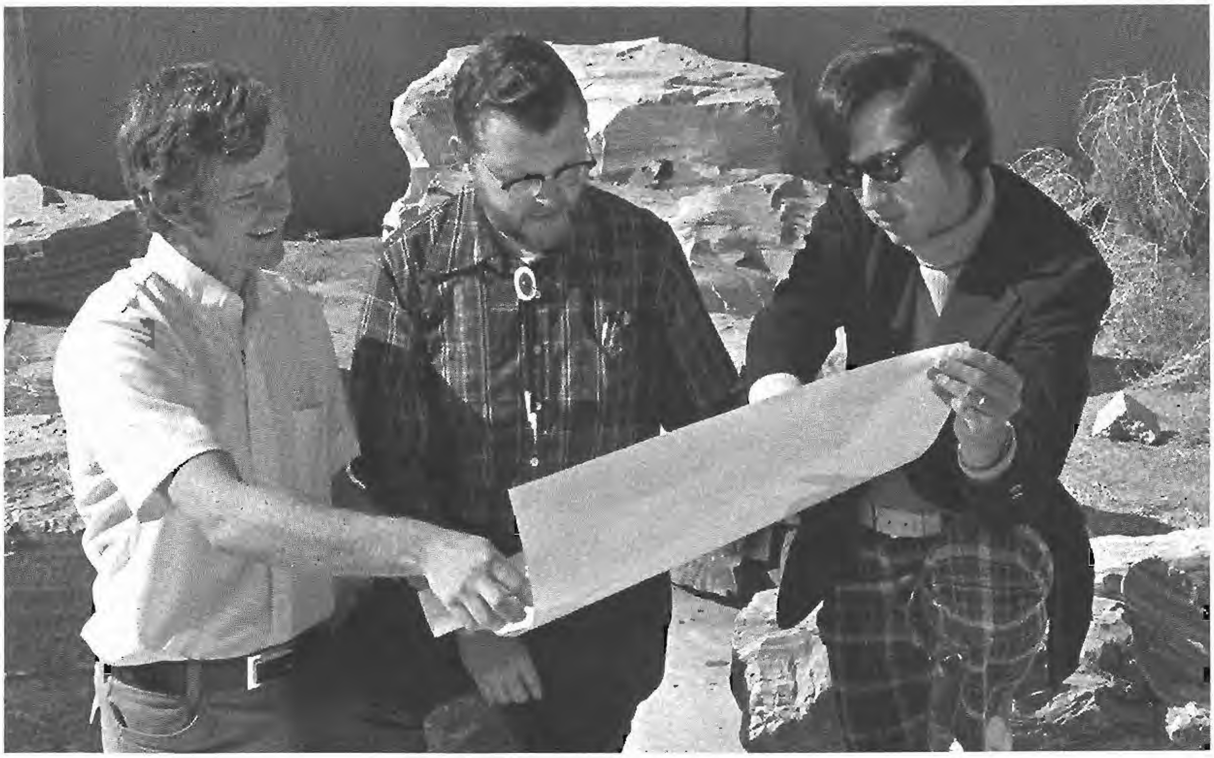
NEW DIRECTIONS

Investigating better ways to obtain fossil fuels, Sandia examined the gasification of underground coal deposits, the extraction of oil from oil shale, and exploration for oil under the seas. It provided technical support for proposed underground repositories for nuclear waste, notably the Waste Isolation Pilot Plant (WIPP) in New Mexico and the Yucca Mountain repository in Nevada. As a hedge against future oil embargoes, it investigated underground storage of oil reserves. While its earlier weapon, verification, and solar energy projects looked up at the skies and into deep space, these new geologic projects looked down into the earth's interior.

Formation of ERDA in 1974, administratively merging the AEC laboratories with the Bureau of Mines laboratories, opened new opportunities for Sandia. Having lost Air Force funding for their carbon-carbon materials research, Hap Stoller and Dave Northrop reasoned that their experience in using methane to create carbon composites might well be reversed to studies of using carbons such as coal to create gases. They visited the Bureau of Mines laboratory at Laramie, Wyoming, then investigating in situ coal gasification — burning coal underground to create fuel gases. Laramie's management took an interest in Sandia's various sensors, like the seismic sensors used in Vietnam, to achieve a better understanding of what happened underground when coal deposits were burned. Wendell Weart and Lynn Tyler prepared a proposal, and in early 1975, Sandia received its first fossil energy funding for developing instruments and controls for the in situ processing of coal deposits and oil shales.

Sandia's work began with evaluation of sensors and measurement techniques at a coal gasification experiment at Hanna, Wyoming. The team of field instrumentation

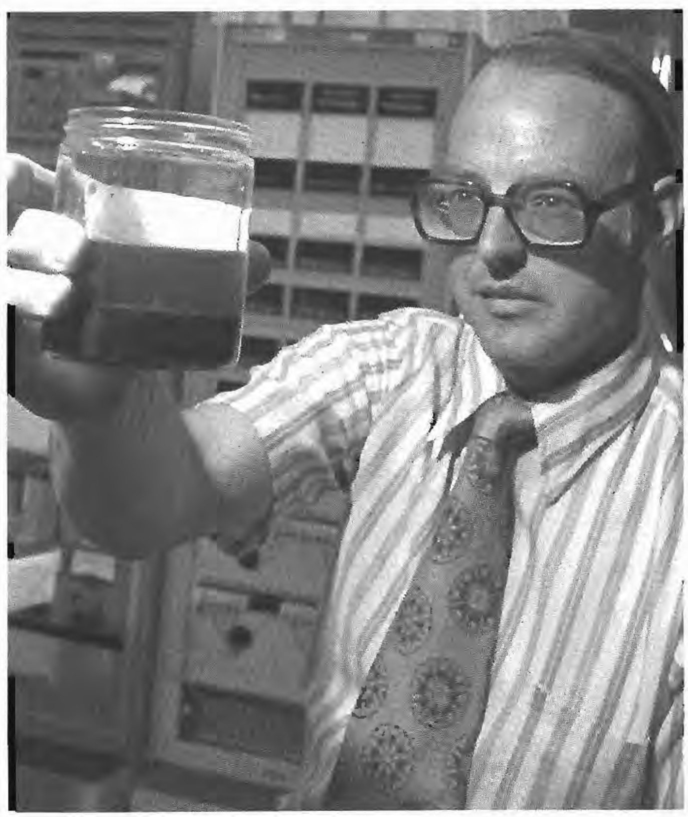
Dave Hawn and Jim Lyons in 1977 load coal slurry into Sandia's coal liquefaction test module.



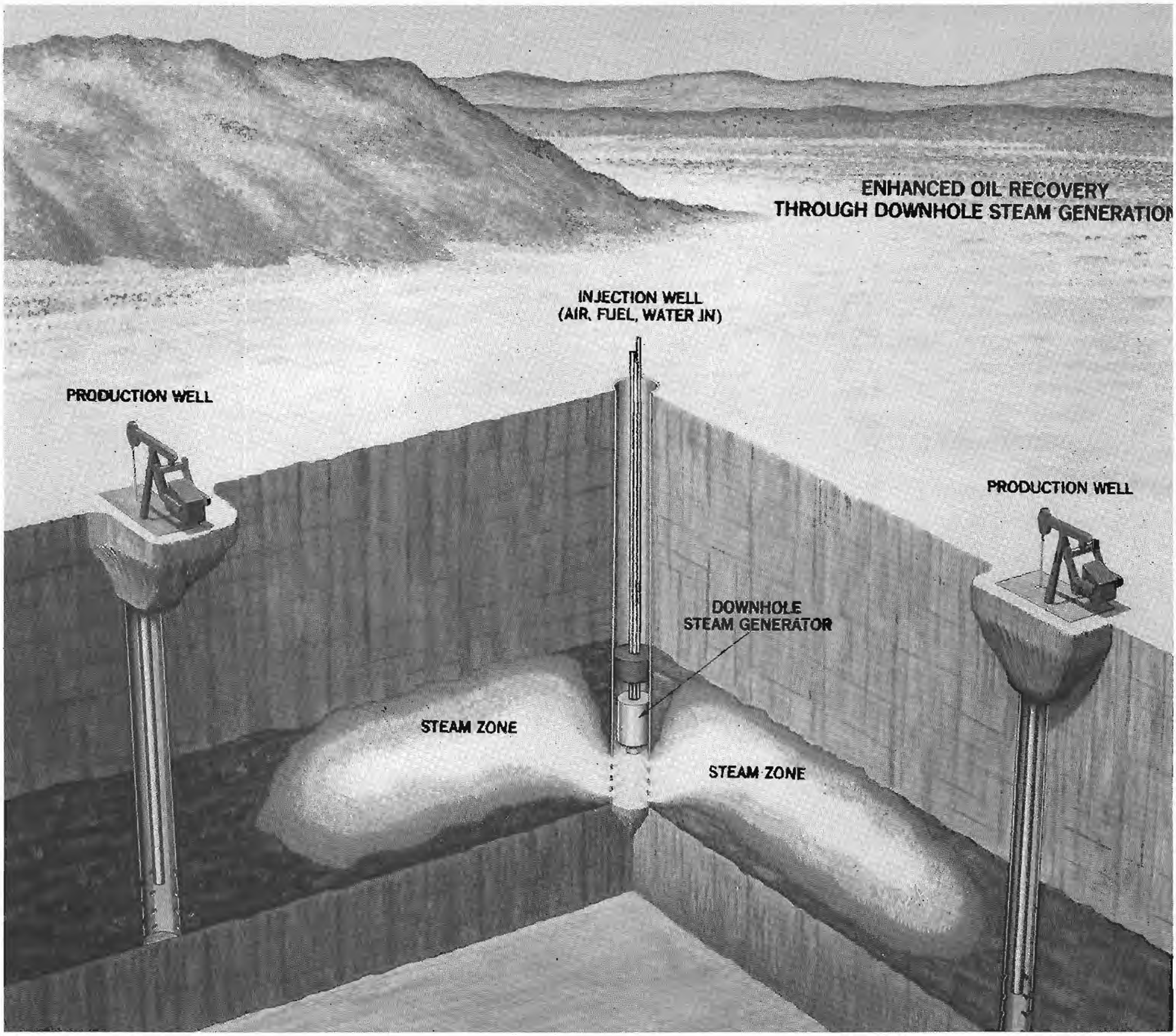
In 1974, Dave Northrop, Wendell Weart, and Hap Stoller examine plans for Sandia's oil shale research.

personnel, led by Northrop, installed sensors on the surface and in wells to pinpoint the location of the underground burn front, allowing the injection of air at the proper place and time to enhance gas production. Studies also began of the combustion chemistry and mechanisms. In later years, the research expanded to include coal-mine subsidence, coal conversion to liquid fuels (synthoil), and related catalytic and geotechnical issues.

A similar initiative involved development of immense oil shale deposits in Colorado, Wyoming, and Utah. Rather than mine this shale, which releases oil (kerogen) when heated, Sandia investigated heating it underground, thereby avoiding the cost and environmental consequences of mining it. Under this plan, explosives turned the shale to rubble and a fire set atop the rubble heated the rock, which then released the oil for pumping to the surface. This was a partially mined, vertical retort method in which Sandia worked with Occidental Petroleum near Parachute, Colorado. Sandia studied how best to fracture the shale and how to control the fire to heat the rock and maximize the oil



Dick Traeger holds a jar of liquid fuel produced from coal in 1977 as part of Sandia catalyst research.



Sandia during the late 1970s designed a downhole steam generator that could be used to enhance oil recovery as shown in this diagram.

released. Virgil Dugan analyzed the economics of this process, Jim Dossey reviewed shale fracturing techniques, and Northrop studied the process chemistry, while Weart coordinated the field experiments.

The oil shale investigations began in cooperation with the Laramie Energy Research Center at oil shale formations, notably at Rock Springs, Wyoming and near Vernal, Utah. Sandians led by Al Stevens provided the diagnostic instruments, rock mechanics expertise, and analysis of explosive fracturing and subsequent retorting of shallow oil shale strata. The Laramie Center and Sandia conducted combustion experiments. Private companies involved included Talley Frac of Greenriver, Wyoming and Geokinetics of Vernal, Utah.

Sandia built oil retort models in the laboratory, and during the second phase, Larry Teufel, Thomas Bickel, Paul Hommert, and associates developed means of recovering as much as ninety percent of the oil from the shale. Hommert predicted that this technology would become attractive "when the price of oil rises again — as it almost surely will."

Other Sandia ventures into fossil fuel research aimed at providing industry with direct means of recovering oil. Richard Traeger in 1978 managed an enhanced oil recovery effort, for example, involving the design of a downhole steam generator, dubbed Deep Steam. Through a process called steam flooding, the oil industry thinned heavy oil with steam injected into wells to permit pumping the oil to the surface, but the steam cooled as it traveled down wells thousands of feet deep. Traeger's team developed a steam boiler small enough to fit inside a borehole and operate at the bottom of wells. Fuel was pumped down to a combustion chamber where it was mixed with air, then ignited by a sparkplug-like device. Injected water mixed with the combustion gases and flashed into steam, thinning the oil for pumping. Ron Fox and Burl Donaldson successfully tested a prototype downhole steam generator near Bakersfield, California, in 1979, and in 1982 Bill Marshall announced that eight companies had begun marketing downhole steam generators commercially to enhance the recovery of existing petroleum resources.

Offshore oil exploration received Sandia's assistance through application of its terradynamics and sensor capabilities. Exploratory drilling for underwater oil required dealing with storms, icebergs, and seafloor earthquakes, but "if the decline in domestic production of oil and gas is to be halted," said Eric Reece, "increased attention must be given to locating new sources." Reece became responsible in 1977 for devising acoustic instruments that could relay data about conditions at the bottom of the seas to acoustic buoys at the surface. Sponsoring this and related research was the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and a consortium of petroleum exploration companies.

As designed and tested in the Pacific, the seafloor earthquake measurement system stored information about seismic activity, then transmitted it on command to a surface buoy for relay by radio to receiving stations aboard ships. Preliminary findings indicated that the shaking from earthquakes was less beneath the sea than on land and that earthquake movements in the seafloor tended to be horizontal compared to the vertical movements seen ashore. This information proved useful to engineers designing offshore drilling platforms.

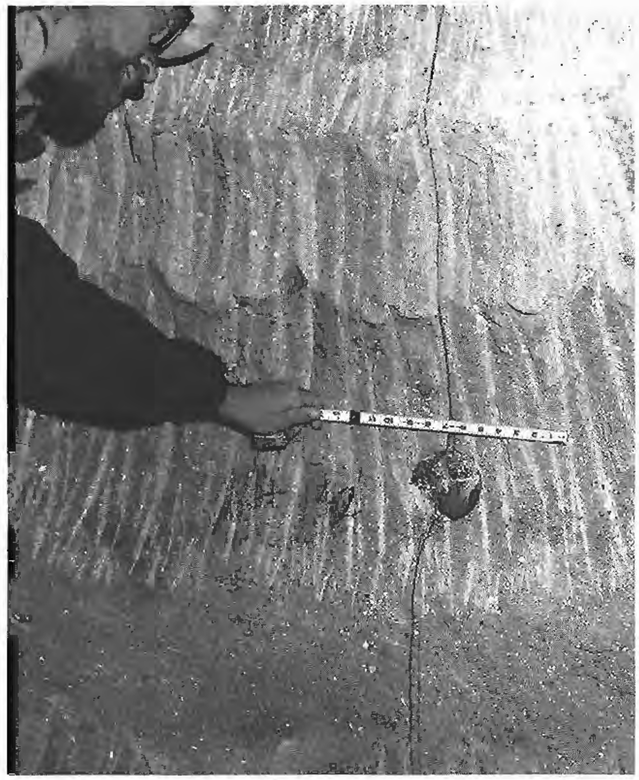
Meanwhile, Max Newsom and colleagues modified the Davis gun design for underwater explorations, driving a penetrator into the seafloor with instruments to measure and transmit information on the shear strength, composition, and dynamic properties of the sediment in which it was embedded. This

Test of a Sandia seafloor penetrator in the Gulf of Mexico. This eight-foot long penetrator could drive 150 feet into the sediments underwater.

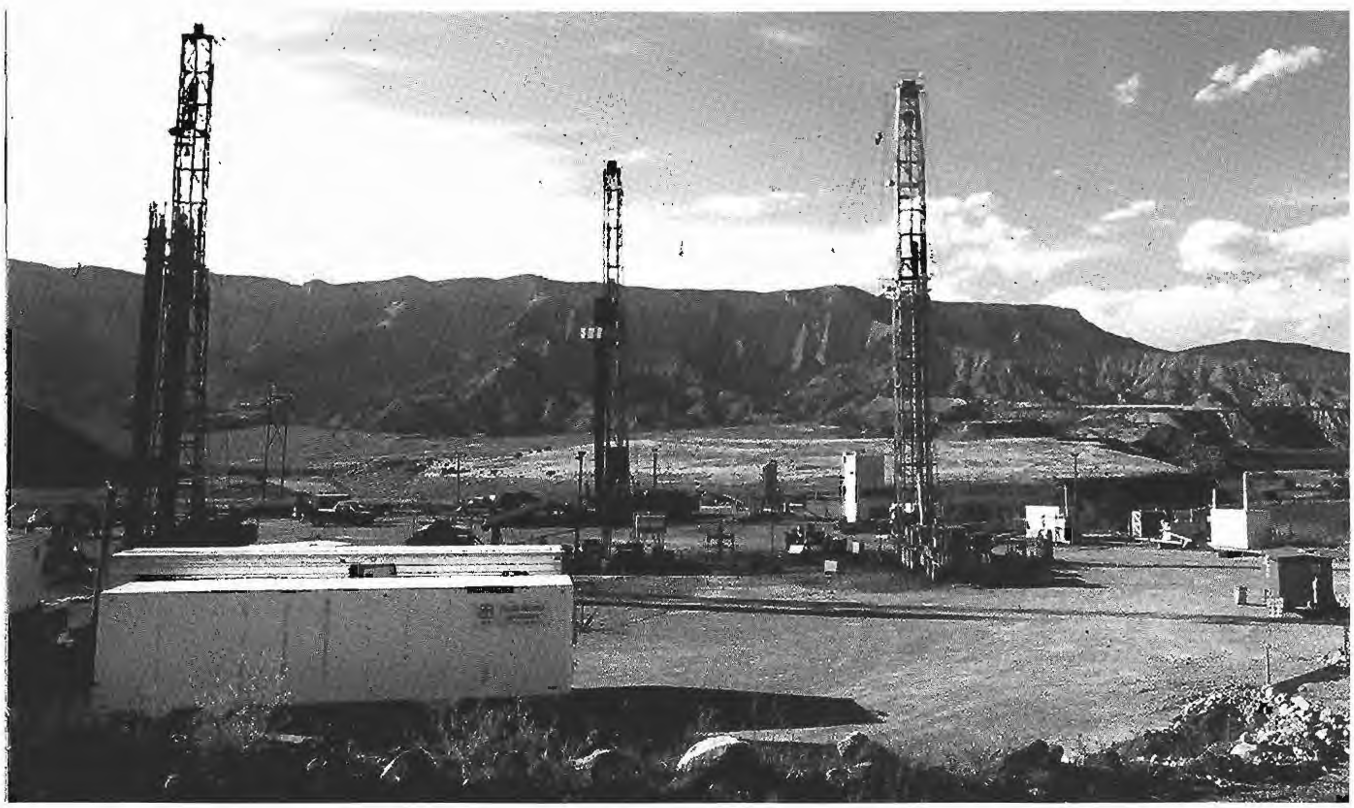
system provided the first sonic-velocity measurements in gas-bearing ocean sediments to the seismic-exploration industry.

Another new direction undertaken by Sandia was work with hydraulic fractures. By 1974, Carl Schuster's division's work on seismic and acoustic sensors for use in Vietnam was coming to an end and the group was moved intact into Jim Scott's newly formed energy directorate. With funding from ERDA's Unconventional Gas Recovery program, they applied the technology to mapping massive hydraulic fractures — a developing method to improve production from natural gas reservoirs. The first efforts were done with Amoco in the Wattenberg Field, northeast Colorado, but tests later took the group to field sites all over the U.S. and Alaska. This remained an enduring technical challenge, with work still continuing 20 years later, by then under funding from the Gas Research Institute.

In the late 1960s and early 1970s, Sandia conducted underground nuclear effects tests



Bill Vollendorf, geologist and guru of G-Tunnel at the Nevada Test Site, measures a mined-out hydraulic fracture.



Three workover rigs on the three close-spaced wells at the Multiwell Experiment site near Rifle, Colorado. In the background are the oil shale cliffs of the Green River formation, site of many Sandia oil shale projects.

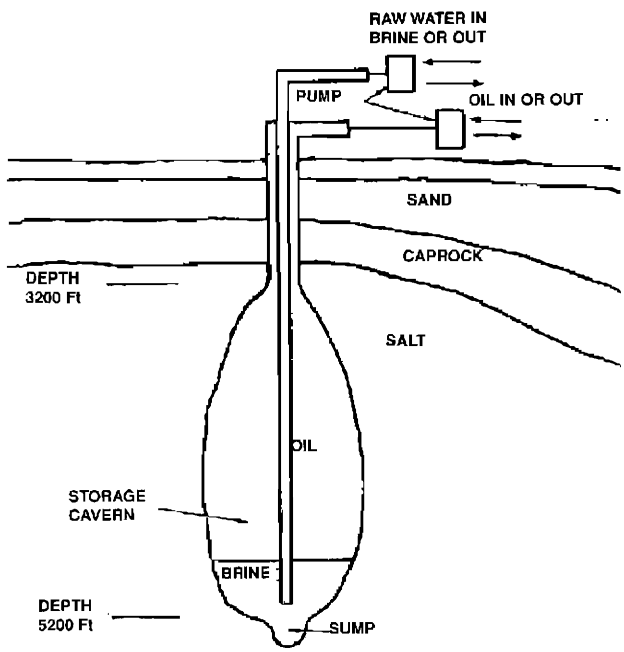
in G-Tunnel at the Nevada Test Site. To assure containment of these tests, Lynn Tyler conducted small-scale fracture tests to obtain stress and related data. At the same time, Halliburton and other oil field service companies developed hydraulic fracturing technology to stimulate the flow of oil and gas from deep wells. Northrop recognized that G-Tunnel offered a unique opportunity — the chance to create fractures under realistic geologic conditions and then mine back through them to directly observe their behavior. Even though Halliburton engineers had created tens of thousands of fractures in the oil patch, they actually saw their first hydraulic fracture at G-Tunnel.

Several years of experiments conducted by Norm Warpinski uncovered many phenomena associated with deep wells, a notable achievement being the demonstration that earth stresses control hydraulic fracture behavior. Rich Schmidt, Jerry Cuderman, and Warpinski also showed the feasibility of multiple radial fracturing from a well by controlled pressurization of the wellbore. These were unique experiments. As Northrop told hundreds of industry visitors between 1976 and 1988, "a picture is worth ten thousand words, but a visit to G-Tunnel is worth ten thousand pictures."

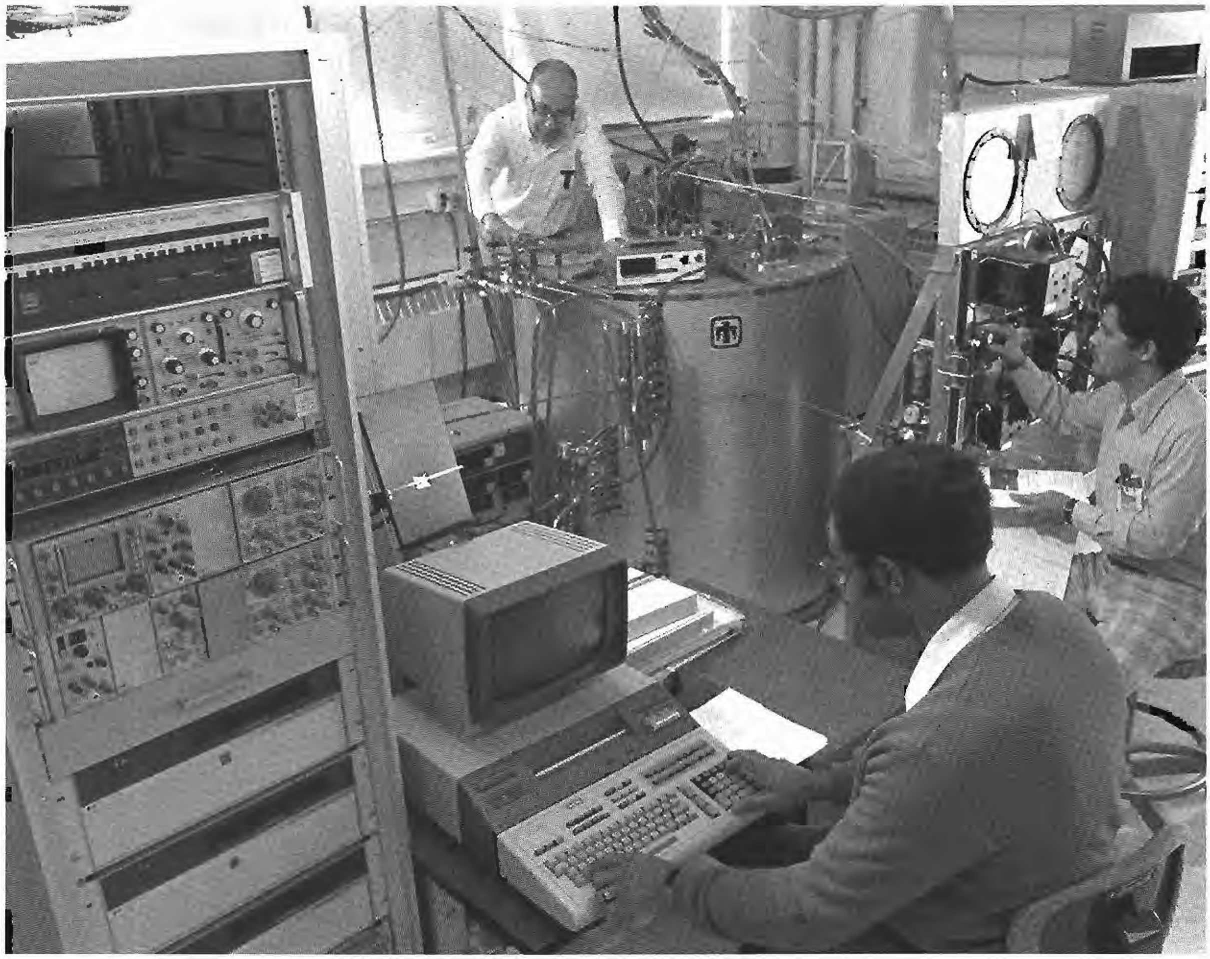
The diagnostic and mineback efforts came together in 1980-1988 when Sandia managed DOE's Multiwell Experiment — an eight-year, $35 million field laboratory for recovery of gas from low-permeability reservoirs typical of the Rocky Mountain states. Northrop, Warpinski, John Lorenz, and Allan Sattler were the core of a Sandia effort that worked together with CER Corporation and a host of other contractors. They performed studies between 4,500 and 8,500 feet depth in three close-spaced wells in the Mesa Verde formation. Key findings included the importance of natural fractures, earth stresses, reservoir geometry, and stimulation methods for gas production from these reservoirs. The wealth of results and insights have been transferred to many companies that are economically exploiting this resource today.

STRATEGIC RESERVES

As a hedge against future shortages, Congress after the 1973 oil embargo approved plans to establish a strategic petroleum reserve, using cavities in salt domes along the Texas and Louisiana coast as huge storage chambers. Although not initially involved, Sandia received an assignment in the program after an accident and fire at one of the storage caverns in 1978. On receiving a request for an independent technical assessment of the program, Jack Howard and Jim Scott over a weekend formed a team led by Jim Ney that went to Louisiana immediately and began a three-month investigation. When DOE accepted Sandia's recommendations and requested continuing studies, Sandia formed a group under Ney's management to undertake studies of the geological, geographical, and hydrological features of salt domes, perform analysis of dome interiors, develop models to assess cavern stability, and consider improved excavation techniques for the storage reservoirs. "The



In 1979, Sandia participated in the design of oil storage cavities in salt domes, as shown in this diagram, for the Strategic Petroleum Reserve program.



Jacque Hohlfelder, Jim Johnson, and Ray Villegas in 1979 conduct a laboratory experiment testing the effects of heat on brine migration in salt, information important for WIPP and the Strategic Petroleum Reserve.

reservoirs are large engineering projects involving unusual underground structures," Morgan Sparks observed, noting that the oil exporting nations strongly objected to the program, because "they consider it a threat to their cartel operation."

The original oil storage used existing commercially leached caverns and one salt mine in the salt domes. Ney's team explored additional sites to expand storage capacity. "Our game plan," Ney said in 1980, "is to have up to 750 million barrels." The new cavities were opened through leaching with water (water dissolves salt; oil does not). After drilling wells deep into the saltbeds, water pumped down the wells dissolved the salt into brine that was pumped out, leaving space for oil storage. Following the early 1980s, Sandia teams led by Jim Linn continued the geological site investigations of existing and potential new sites. These teams developed new leaching codes, conducted cavern testing and cavern monitoring, and improved salt creep modeling capabilities. By 1991, about 660 million barrels were stored and the mere threat of using the reserve, coupled with a sample sale, was sufficient to help stabilize world oil prices during the Persian Gulf War.

NEW NUCLEAR DIRECTIONS

Sandia's principal environmental studies were in support of nuclear power. These included three programs begun in the mid-70s: sewage sludge irradiation, the Waste Isolation Pilot Plant, and the Yucca Mountain project.

The sludge irradiation project sprang from the planetary quarantine thermoradiation research of the late 1960s, which emanated from Sandia's preoccupation with cleanliness when close-tolerance parts and electronics were manufactured for weapon components. Indeed, Willis Whitfield, inventor of the clean room, provided leadership in all three programs.

Sludge irradiation sought to solve two environmental problems: disposal of sewage sludge and of radioactive wastes. As Jack Sivinski put it, "We are taking what have been two national liabilities and turning them into national assets." The concept involved using cesium-137, a byproduct of reactor operation, to decontaminate sewage sludge. The decontaminated material could then be used as fertilizer or as an animal feed supplement.

In an effort to obtain cleaner water, Congress had enacted environmental legislation during the early 1970s requiring the secondary and tertiary treatment of sewage before it entered rivers and lakes. An environmental consequence was rapid growth of the amount of sludge produced at each treatment plant; by 1979, for example, Albuquerque generated fifteen tons of sludge daily. While the Massachusetts Institute of Technology investigated the use of electron beams to treat sludge, Sandia explored the use of gamma rays from encapsulated cesium-

Clockwise from left: Jim Pierce, Willis Whitfield, Marvin Morris at the Sandia Irradiator for Dried Sewage Solids (SIDSS) in 1977. It was a pilot plant testing the use of gamma rays to treat municipal sewage.

Willis Whitfield and Jacek "Jack" Sivinski in 1976 inspect a crop fertilized with thermoradiated sludge.

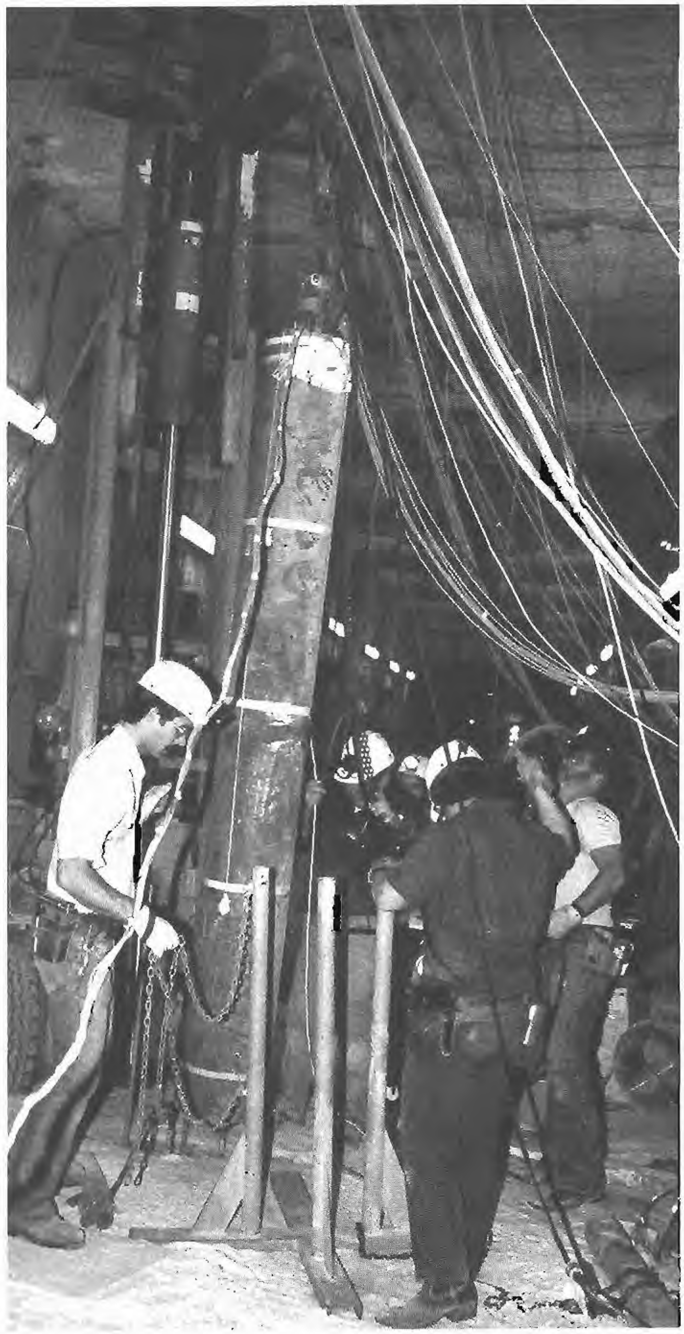
137 to destroy viruses and bacteria, making it more usable. With DOE funding, the Sivinski-Whitfield team built a prototype sludge irradiation facility that passed buckets of sludge on a conveyer through a field of cesium-137 radiation. After the cesium killed the microorganisms, the sludge could serve as soil conditioner, or even be pressed into pellets as feed supplement for cattle. This did not make the sludge radioactive, any more than having a chest x-ray makes a person radioactive.

Senator Harrison Schmitt of New Mexico, when dedicating Sandia's sludge plant prototype in 1978, declared that sludge and nuclear waste should in the future be considered resources in disguise. Although Albuquerque sought funding to construct a similar operational plant, sludge treatment with cesium radiation remained a neglected technology. Sandia then converted its prototype sludge-treatment plant to studies of using irradiation to destroy pests in fruit for the Department of Agriculture.

Evaluation of nuclear waste disposition alternatives from both the defense and the energy sectors began during the late 1950s. Among the alternatives considered were rocketing waste into deep space and burying it at the ocean's bottom. Sandia had a major role in investigating the seafloor disposal concepts, including using its penetrators to explore seafloor geology. Richard "Rip" Anderson supervised the seabed programs division, investigating techniques for placing, monitoring, and retrieving the canisters. The ocean floor was studied extensively in a search for geologically stable and biologically inactive deep ocean sediments. However, environmental concerns and the decision to investigate one site at a time, focusing first on Yucca Mountain, halted the program in 1987.

About 1970, Oak Ridge National Laboratory recommended that the radioactive wastes be stored in saltbeds in Kansas. Because it is imperative that nuclear wastes have no contact with ground water, saltbeds, which by their very existence imply no circulating ground water, seemed a logical choice for the burial site. When it became evident that numerous boreholes had been drilled through the saltbeds in Kansas, however, DOE began searching for other suitable sites.

By 1975, the search had focused on saltbeds that were about two thousand feet deep in New Mexico near Carlsbad, and Sandia received the assignment to investigate



Engineers and technicians at WIPP lower a canister containing an electric heater into the underground saltbed to explore the salt's reaction to heat.

this site. Wendell Weart of Sandia's underground physics division took charge of the WIPP project, initiating drilling and geologic investigations near Carlsbad. When full-scale studies of the Waste Isolation Pilot Plant were approved in 1977, Sandia made Orval Jones manager of a group responsible for technical support of DOE planning for underground depositories. Among these were both WIPP and the proposed Yucca Mountain project in Nevada. "WIPP is like a new phase 3," Jones remarked, explaining, "This is a technical project of major proportions which will fully exercise our systems engineering capabilities."

Sandia continued its geological studies at the site and began testing transportation and storage equipment in Albuquerque. In 1980 Congress enacted legislation authorizing construction funds for WIPP as a defense project. President Carter signed the bill, then declared that he would not support construction at the WIPP site until at least two other sites were examined. Morgan Sparks lamented: "We're in the middle of a controversy between the Congress and the President and will have to ride it out until a single position is achieved. It makes for difficult planning and working." As anyone who tracked the serpentine course of WIPP through Congress, the courts, and regulatory agencies could attest, it proved to be "difficult planning and working," indeed.

No less controversial was the Yucca Mountain project, although this controversy lagged a decade behind that at WIPP. The search for sites suitable for isolating high-level nuclear waste began in 1976, and Sandia's early research under Dick Lynch examined argillite, volcanic tuff, and other rocks characteristic of the Nevada Test Site. Al Lappin and colleagues in Sandia's geological group sought to determine whether the thermal and mechanical properties of these rocks made them suitable as a disposal medium. Not until Congress enacted the Nuclear Waste Policy Act in 1982 and the number of potential storage sites was reduced to nine, then three, and finally to the tuff of Yucca Mountain did the controversy grow to WIPP proportions. In the 1970s, however, Sparks expressed optimism about nuclear waste management. "It is a difficult problem, requiring a lot of work and quite a bit of money," he admitted, "but it is not insoluble, and I think it can be done in a safe way."

TECHNOLOGY SPINOFFS

In addition to applications of its weapon-based expertise to energy and environmental waste management solutions, Sandia undertook renewed efforts aimed at making this technology available commercially. Corry McDonald managed Sandia's industrial cooperation and technology utilization program during the 1970s, with assistance from Patrick Quigley, Gene Emerson, and others. Although these early efforts at technology transfer were hampered by a lack of funding, they had a few successes. The media took great interest, for example, in the application of weapon technology to biomedical engineering.

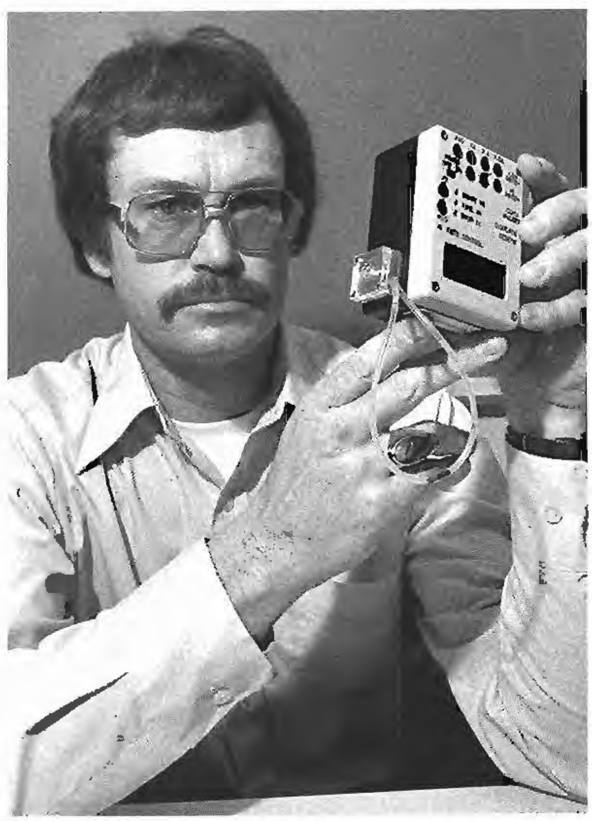
Although Sandia had never specialized in life sciences, university medical schools during the late 1970s requested its assistance in developing equipment that might be used in cancer and diabetes therapy. Request for assistance with cancer research came, for example, from a Texas A&M executive who had used a Sandia-furnished neutron generator in experiments and said, "That first neutron generator was the only piece of equipment I ever bought that worked exactly the way it was supposed to the first time I turned it on." On his recommendation, the National Cancer Institute in 1976 sought Sandia's help with the development of a portable, intense neutron source. Frank Bacon and a Sandia team sought to redesign neutron generators, Zippers, from weapons as portable sources for neutron therapy. These generators, used to initiate nuclear reactions, were tiny particle accelerators. They accelerated a beam of deuterium and tritium ions against a metal target loaded with deuterium or tritium, and the resulting collisions caused atoms of these isotopes to fuse, generating neutrons that could be used for cancer therapy or other purposes.

Don Cowgill and Frank Bacon in 1979 inspect the target of a neutron generator designed for use in cancer research.

After extensive study, the Sandia team reported it feasible to develop a sealed-tube neutron generator that could be incorporated into a compact rotatable-beam machine for clinical applications. Although interest in neutron therapy for cancer dwindled, this research had other dividends and applications. Ron Hill, for example, solved the problem of focusing the neutrons in a beam useful for patient dosages by devising a variable aperture collimator. Sandia later redesigned these portable neutron generators for non-weapon uses: for logging the boreholes driven in search of uranium and later for use in portal monitors safeguarding nuclear materials.

Another biomedical application was the bionic pancreas developed by Sandia at the request of the University of New Mexico in 1978 to replace the insulin shots typically administered to diabetics. University of New Mexico School of Medicine experiments produced a pump that could release preprogrammed doses of insulin intravenously. Bill Spencer of Sandia, whose daughter suffered from diabetes, became interested in this research by endocrinologist Philip Eaton. Spencer and Eaton obtained funding from the Kroc Foundation, the National Institutes of Health, and the Department of Energy to develop a miniature pump for implantation in diabetic patients, just as pacemakers were implanted in cardiac patients. As Eaton explained, "We needed a pump that could release a low flow of insulin, that was tiny enough to be implantable, and that was totally dependable."

Spencer and a microelectronics team including Jerry Love, Wayne Corbett, and associates first designed a pump using a highly reliable rotary solenoid motor developed at Sandia for weapon use. When this pump proved successful in animals, Sandia's drive to miniaturize the pump began, using programmable computer chips and related components on a ceramic thick-film circuit to reduce it to a size suitable for human implantation. When Sandia



Jerry Love displays an insulin pump developed in 1979 by Sandia and the University of New Mexico. When made small enough for implantation in diabetic patients, the pumps became a commercial spinoff from Sandia's weapons research.

Da Vinci II preparations in 1976. In the gondola are the researchers who were on the flight: Otis Imboden, National Geographic Society photographer; Vera Simons, pilot and project consultant; Jimmie Craig, pilot, Naval Weapons Center; and R. J. Engelmann, NOAA project scientist. Standing in front is the Sandia team: Bernie Zak, scientific director; Preston Herrington, project engineer; Jack Armbrust, safety; Keith Smith, project director; Tex Windham, mechanical systems; Ed Marsh, launch director; Lloyd Kelton, crane operator; and Wayne Hancock, documentary photographer.

completed its pump design in 1981, physicians implanted it in a diabetic to maintain normal insulin levels. Subsequently, Sandia modified the pump — dubbed an artificial pancreas — for manufacturing design and a pharmaceutical firm marketed it commercially, easing the lives of hundreds of diabetics.

Although not a commercial spin-off, another Sandia area of expertise was applied to non-weapons work in the 1970s. Building on its experience in meteorological and altitude research, in 1972 Sandia had engineered scientific packages and designed experiments for unmanned balloon studies of the stratosphere in conjunction with research initiated by the Army's Atmospheric Sciences Laboratory at White Sands Missile Range. Also in the 1970s, in response to growing public and government concern about the state of the environment, ERDA undertook several major projects chronicling air pollution. One of these was Project Da Vinci, a series of manned-balloon flights to track pockets of pollution and determine whether they changed, dissipated, or remained intact as they traveled away from their sources. A balloon offers advantages over other methods of tracking pollution because it can drift with the air without disturbing it or adding any pollution of its own.

The project was proposed by Vera Simons, an artist and balloonist who took her idea to Rudolf Engelmann at the AEC in the early 1970s. Da Vinci became a joint project of ERDA, the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration, and the National Geographic Society. Sandia engineered the scientific payload for Da Vinci I, a short flight in the relatively pollution-free air of New Mexico in November of 1974. For Da Vinci II and III, Sandia agreed to direct the project, with Keith Smith and Bernard Zak serving as project director and project scientist, respectively. These flights were launched in 1976 from Arrowhead Airfield, just outside of St. Louis. St. Louis was chosen because it already was the site of the EPA's Regional Air Pollution Study, allowing scientists to compare information obtained by the balloons with that from the existing monitoring stations. In the end, the flights indicated that smog does not dissipate as it floats away from its source. Instead, it stays together and often gets more toxic as it travels. Although the Da Vinci Project ended after three flights, Sandia remained involved in using unmanned balloons for pollution studies under Zak's guidance.

INTERNATIONAL ARMS CONTROL

Since the early days of the VELA program, Sandia had designed sensors to support verification of international arms control agreements. Paul Stokes and a Sandia task force acted as technical consultants to the U.S. delegation to the arms control negotiations leading to the 1972 strategic arms limitation treaty (SALT I). In 1973 the U.S. Arms Control and Disarmament Agency funded Sandia's development of unmanned seismic observatories, a technology important in reassuring treaty signatories that nuclear test restrictions could not be violated without detection. The first seismic stations that Sandia deployed during the 1960s recorded data on magnetic tape that had to be retrieved every four months. Sandia's goal during the second phase was to design seismic observatories that could transmit data to satellites in orbit. In 1978, the satellite design group installed a prototype seismic station in Tennessee to collect ground motion data and transmit it via satellite to receivers in Albuquerque. Further development of these seismic detectors continued into the 1990s.

The Threshold Test Ban Treaty of 1974, limiting the yield of underground tests to 150 kilotons, and the adjunct Peaceful Nuclear Explosion Treaty of 1976 added impetus to Sandia's verification research. Because the terms of the latter treaty allowed on-site monitoring of peaceful nuclear explosions to ensure treaty compliance, Sandia, Los Alamos, and Lawrence Livermore worked with ERDA's Nevada Operations Office to develop yield measurement and seismic systems. The laboratories developed portable seismic sensors and versions of the SLIFER diagnostic system; prepared recording trailers and field instrumentation; and certified the equipment's capabilities during the REDMUD event at NTS. Although not deployed to the Soviet Union, this equipment was used on other NTS events to maintain operational readiness.

Under the Nuclear Non-Proliferation Treaty, the UN's International Atomic Energy Agency (IAEA), headquartered at Vienna, Austria became responsible for detecting nuclear capabilities that were in violation of the treaty, and the IAEA asked for Sandia's assistance. Among the tasks assigned to Sandia were the design of special seals that could reveal tampering with nuclear containers, devices to detect the movement of nuclear fuel bundles, and sophisticated tamper-resistant surveillance equipment. Jim Ney, who managed this effort, explained that it monitored activities by using "unattended instruments which continuously collect operational data and monitor areas of infrequent activity or hard-to-get-to locations."

Responsibility for international safeguards was added to Bill Myre's security

Paul Stokes and Roger Hagengruber served as technical advisors in 1978 to arms control negotiators in Geneva, Switzerland.

systems directorate, already tasked with designing security systems for protecting nuclear weapons and materials from terrorist attacks. "With the growing concern over proliferation of nuclear weapons abroad, we're developing highly reliable, long-lived surveillance and containment instrumentation for the IAEA," said Myre. "While the equipment is often different from that used to thwart terrorists, the objective is still deterrence."

A major thrust of the early Carter administration was negotiation of a treaty banning all nuclear weapon testing. To assist in monitoring such a treaty, Sandia joined with Los Alamos during the late 1970s in designing sensors to be flown on the Global Positioning System (GPS) and Defense Support Program (DSP) satellites to replace the VELA satellites of the 1960s. Sandia's atmospheric nuclear burst detection package was oriented earthward, while Los Alamos's sensors monitored surrounding space for nuclear detonations.

For the GPS satellites, Sandia also designed radiation-hardened, large-scale integrated circuits that could replace 100 standard integrated circuits in logic systems for data processing and command and control. Although the first of these satellites was not launched until 1983, Roger Hagengruber and Paul Stokes were in Geneva providing technical support for arms control negotiations, and their reports convinced Morgan Sparks and other Sandians by 1978 that a comprehensive test ban would eventually be signed. When public concern arose about how this might affect Sandia,

A monitoring trailer prepared in response to the Peaceful Nuclear Explosions Treaty is test-loaded on a stretch C-130 at the Nevada Test Site.

Scientists from Germany in 1978 examine a surveillance camera developed at Sandia with Bill Myre, *left,* and Jim Ney, *right,* holding the camera.

Tom Cook pointed out that less than five percent of Sandia's activities involved nuclear testing. "Decreases in testing activities," Cook correctly predicted, "might well be offset by increases in simulation and verification efforts."

ENERGY CRISIS

When Iranians seized the American embassy in Tehran, took hostages, and stopped oil exports to the United States, higher energy prices and a second energy crisis followed. During this crisis, President Carter and Secretary of Energy Schlesinger mandated additional reductions in the use of gasoline and electricity at federal facilities, including Sandia; and Ward Hunnicutt, Sandia's plant engineer, instituted extensive energy conservation efforts.

Sandia's energy research received boosted funding, thanks to an ambitious initiative by the Carter administration to increase the use of solar energy and other alternatives to petroleum. When Vice President Walter Mondale visited Sandia in 1978, he took time to highlight its solar and alternative energy projects. The Energy Security Act of 1980 went farther, creating a corporation to subsidize synthetic fuel production from coal and oil shale, encouraging the development of alcohol and methane substitutes for petroleum, and providing tax credits for solar

Vice President Walter Mondale visited Sandia's solar research facilities in 1978. *Foreground from left:* Morgan Sparks, Mondale, Herman Roser, Governor Jerry Apodaca, Senator Pete Domenici.

and energy conservation installations. Finally, the legislation authorized the President to begin filling the Strategic Petroleum Reserve. These energy conservation and related measures had some impact: in 1980, U.S. petroleum use decreased and its total energy consumption actually declined by four percent compared with 1979.

A NATIONAL LABORATORY

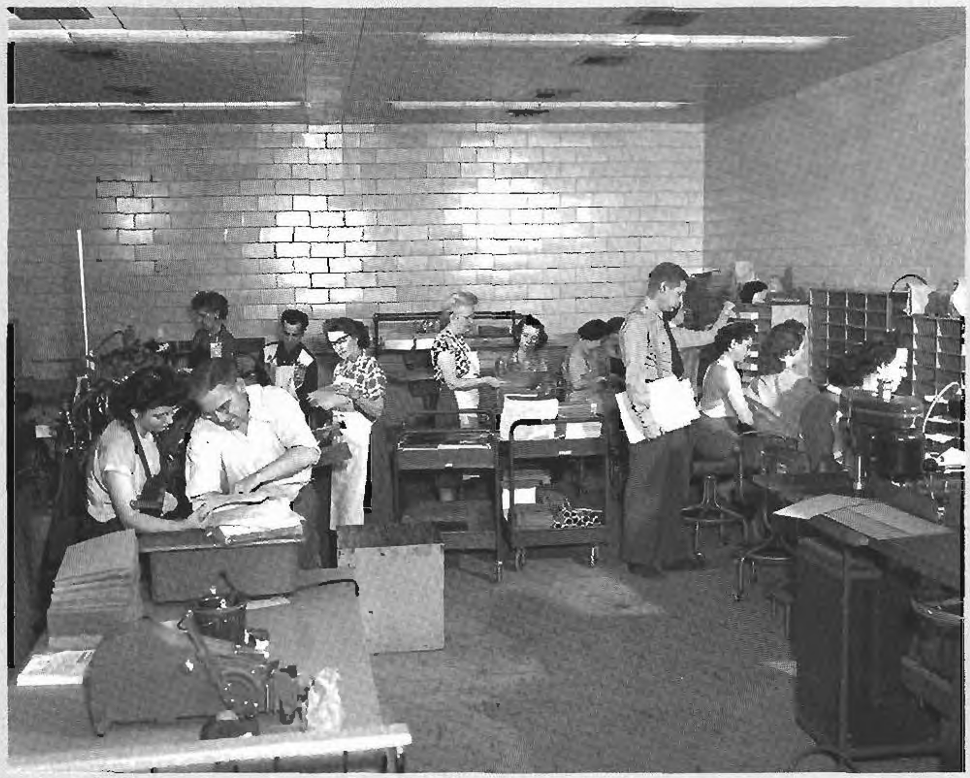
During the coldest days of the 1979 energy crisis, Sandia acquired national laboratory status. Quietly included in legislation Congress enacted during the December 1979 holiday season, the name change to Sandia National Laboratories surprised most Sandians.

The Atomic Energy Commission in 1946 and 1947 had established the first national laboratories at Argonne, Brookhaven, and Oak Ridge. These were managed by universities or associations of universities, and national laboratory status indicated that they engaged in broad, multiprogram research in close association with the universities. Congress subsequently added the Idaho National Engineering Laboratory, the National Renewable Energy Laboratory, and others to the list. Although Los Alamos and Lawrence Livermore laboratories were managed by the University of California, they did not officially become national laboratories until 1979, when they received that status in the same legislation as Sandia.

Considerable political pressure in early 1979 urged the University of California to end its management of the two nuclear weapon laboratories, and Governor Edmund "Jerry" Brown called for the University to divest itself of Los Alamos management entirely while diverting Lawrence Livermore into non-weapon programs. John Deutch, the Undersecretary of Energy, expressed concern about Brown's proposal, and Senator Henry "Scoop" Jackson was so disturbed that he supported legislation directing DOE to consider hiring new contractors for laboratories' management. "These laboratories are a national asset — they do not belong to a university, a state, or a region," Jackson declared, arguing that they were the cornerstone on which national security rested. "Since the early 1950s, Los Alamos, Lawrence Livermore, and Sandia Laboratories have kept this country well out in front of its potential adversaries," Jackson asserted.

When bills in the House and Senate were drawn to confer national laboratory status on Los Alamos and Lawrence Livermore, Leonard Jacobvitz and James Stout from the DOE Albuquerque office insisted that Sandia also be designated a national laboratory. When Congress enacted the bill naming the three as national laboratories at the end of December 1979, the change proceeded with little fanfare at Sandia. Morgan Sparks pointed out, however, that Sandia had become not only a national laboratory, but with 7,700 employees on the last day of the 1970s it became the largest national laboratory as well.

Asked how Sandia National Laboratories could best serve the nation during the coming decade, Sparks responded: "The nation is entering the '80s with much apprehension. Beyond the state of the economy, the two biggest problems we face are the adequacy of our national defense and our energy supply. We at Sandia have a marvelous opportunity to contribute to both of these challenges. What more could we ask for?"



The Sandia Print Shop as it appeared in 1952. Workers took care of printing, collating, binding, and mimeographing under the supervision of Art Perry, standing at right.

Graphic Design, Tech Art, Tech Writing, and the Print Shop

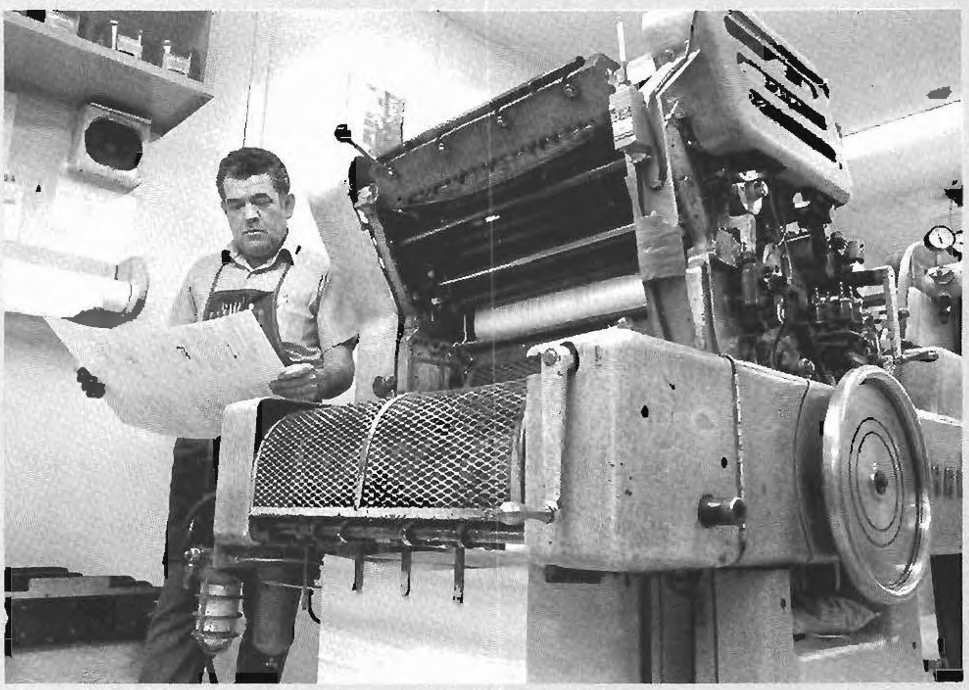
The production of manuals, technical reports, exhibits, brochures, and the glossy magazines detailing technical achievements over the years rests with Sandia's in-house graphic designers, technical artists, writers, compositors, and printers. The majority of the work has focused on technical reports and weapon manuals. The careful presentation of Sandia's work to the military and others in the nuclear weapons business required well-trained and speedy writers, as well as talented artists and photographers.

In 1957 it took about 15 days to produce a technical manual once a rough draft was prepared. While the technical writer finished the draft of the manual, a technical artist would begin making the drawings, and the reproduction workers would prepare copies of the draft for editing. The technical writing, photo and reproduction, and technical art divisions tried to work closely together to keep the publication on track. J. J. "Mike" Michnovicz, Photo and Reproduction Supervisor in 1957, stressed the need for cooperation to meet constantly looming deadlines at a time when the size and number of copies of manuals was on the rise. "Technical manuals in the past have averaged 80 to 120 pages with 800 to 1000 copies required. Currently, the trend is toward 150 to 200 pages with the print order running between 2000-3000 copies."

Once the rough draft was approved, complete with art work and photographs, masters were created and sent to the print shop. Working two fully staffed shifts, the print shop churned out completed manuals almost daily. Although most of Sandia's color printing has been done by outside suppliers, the presses in the basement of building 802 were never idle. Technical reports and weapon manuals remained the bulk of the print shop's work over the years. In 1973, for example, an average of 450,000 pages a week was produced. The end of the Cold War reduced the need for new weapon manuals, but writers and artists were needed to support the variety of other programs undertaken by the Labs.

Right: Sandia's technical artists have won a variety of local and national awards over the years. Here Leo Ortiz is shown with the detailed fulltone color illustration of a Sandia-designed instrument that garnered him first place in the cutaway and color renderings category of the 1963 National Illustrators Management Association exhibit in Los Angeles.

Below: Fred Pena operating a Harris press in the print shop in 1973. At the time, the shop operated two Harris and two Davidson presses for large jobs in addition to three Multilith presses for rapid service.



Sandia California facilities at Livermore in 1984, looking southeast. Across the street in the left immediate foreground is part of Lawrence Livermore National Laboratory.

VII

STRATEGIC DEFENSE

Peace in this world, especially in the nuclear age, is beyond price and must be maintained.

George Dacey

Policy changes implemented by President Ronald Reagan in 1981 affected Sandia significantly. Funding cuts for energy research forced program curtailments, while expanded defense funding bolstered Sandia's weapon programs. The President's 1983 strategic defense initiative (SDI) and the 1984 decision to apply Sandia's nuclear weapon design expertise to the improvement of conventional weapons, added additional funding sources for Sandia.

During the 1980s, the nation and world moved into a new era of mobile missiles, stealth bombers, and smart weapons. National defense policies shifted from offensive to defensive strategies, from nuclear to advanced conventional weapons, and these shifts were mirrored in Sandia's activities. With increasing demands for its expertise and services, Sandia prospered, developing its own programmatic triad: nuclear weapons, energy and environment, and reimbursable work-for-others.

When George Dacey became Sandia's president in 1981, it was rushing to meet the Defense department's schedules for the design and production of three new nuclear weapons: the B83 strategic bomb and the warheads for both cruise and tactical missiles. This presented strenuous challenges, and success in meeting the requirements brought credit not only to Sandia, but contributed as well to international progress in arms control negotiations.

At first, SDI concentrated on development of directed-energy weapons, and this program, coupled with existing weapon effects and fusion research efforts, stimulated major advances in Sandia's pulsed-power research. With additional funding, Sandia designed and built huge particle accelerators for the generation of x-rays as well as electron and ion beams.

In both nuclear and conventional designs, Sandia sought to create "smart" weapons able to find and identify targets and strike them with precision. Dacey described this initiative as a campaign to give weapons an "artificial intelligence," using sensors and computers that added decision-making capabilities to the weapons. This concept also found applications in improved weapon use control, in treaty verification technology, and even in commercial manufacturing.

REAGAN AND DACEY

Declaring that the Department of Energy had never produced a quart of oil or a lump of coal, Ronald Reagan advocated abolishing it. A week after taking office in 1981, insisting that energy shortages resulted from federal interference in the marketplace, he lifted fuel-price controls and rescinded the building temperature restrictions imposed in 1979. Reagan's energy plan emphasized the release of federal energy reserves to production and the funding only of long-range energy research with potentially high payoffs. More important for Sandia, Reagan supported greatly augmented defense programs. In his first year, he reduced the Carter administration energy budget while increasing the defense budget, and he proposed transferring Energy department functions to the Commerce and Interior departments.

At this critical juncture, George Dacey became Sandia's president when Morgan Sparks retired after nine years at the helm. Dacey and Sparks were old friends; indeed, Sparks had been best man at Dacey's wedding. Dacey had designed radar jammers at Westinghouse Laboratories during World War II, and later, while a graduate student at the California Institute of Technology, he accepted William Shockley's invitation to work at Bell Laboratories. He joined the transistor research team that included Sparks and John Hornbeck, acquiring nine patents and becoming an early expert on lasers before transferring to Sandia as research

Sandia president George Dacey, *top*, meets some of his predecessors. *Left to right:* John Hornbeck, Monk Schwartz, Morgan Sparks.

Morgan Sparks welcomes George Dacey to Sandia in 1981. They stand atop Building 802.

George Dacey reorganized Sandia's executive management in 1982. *Left to right*, executive vice presidents Al Narath and Tom Cook with Dacey.

director in 1961. Back at Bell Laboratories in 1963, he became its vice president of operations and planning before succeeding Sparks at Sandia.

Dacey was a forthright optimist, whose personality meshed well with the optimistic character of the Reagan administration. Indeed, his friends described Dacey as another "great communicator," able to speak extemporaneously while clearly communicating the gist of complex technology. When asked how Sandia in 1981 compared with the Sandia of 1961, Dacey observed that in 1961 only a quarter of its technical staff had advanced degrees, but this percentage had increased to about three-quarters by 1981. Moreover, Sandia had many more computers and modern instruments than it had in 1961. "If you look at the degree to which analysis rather than empirical methods inspires our work, we are much further ahead," Dacey noted, "In almost every technical sense, we are both a broader and deeper technical laboratory than we were then."

Dacey personally deplored the Reagan administration's cut in funding for energy research. "It seems obvious to many of us," he said, "that unless the nation wants to depend increasingly and indefinitely on foreign sources of oil, then there is an energy problem." When the decline continued for several years, however, adjustments became necessary at Sandia. Sandia centralized its management of solar central receiver programs at Albuquerque, for example, and transferred staff from fossil energy programs to other programs such as the Yucca Mountain high-level waste repository studies. According to vice president John Galt, Sandia shrank its energy programs and expanded defense programs in ways that reduced the pain: "We had reached the place where we had a fair number of retirements, so that the problem of having people who were rendered obsolete by the change was minimized, and the upshot of the whole thing was a very smooth adjustment."

To further compensate for the diminishing energy workload, Dacey urged that Sandia accept reimbursable work from agencies outside of the Department of Energy. In time, reimbursables could serve an inertial role, he reasoned, damping budgetary oscillations resulting from transitions in national energy and defense policies. "It takes decades to build a laboratory like this one where the skills complement one another, where complicated jobs can be done on a multidisciplinary basis, and where people have learned how to work effectively together," Dacey observed. "That kind of an institution represents a national resource that deserves to be preserved; it's not easy to rebuild such a place if you dismantle it."

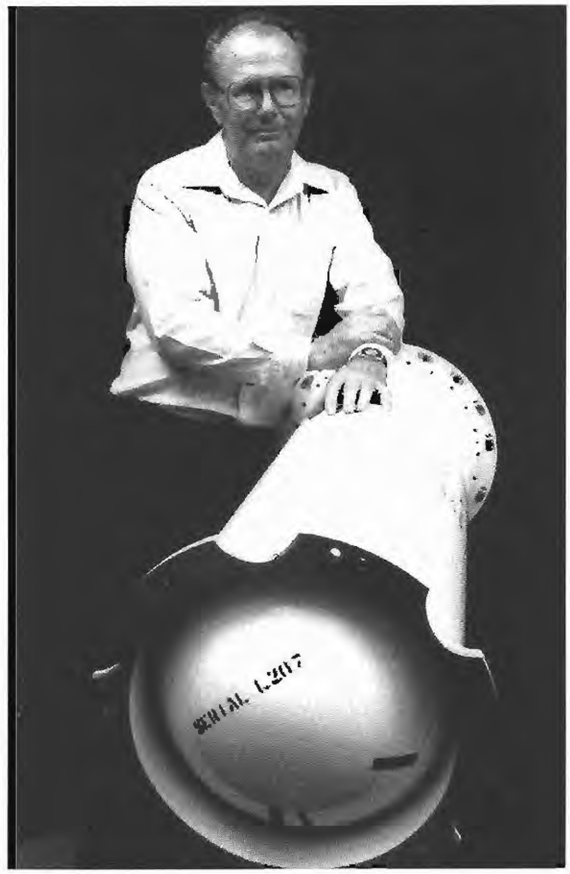
George Dacey and his executive staff (small staff) in 1983 listen to Bob Reuter, *standing*, speak on Sandia's recruiting program. *Seated at the table from left to right:* Gene Reed, Bob Peurifoy, Charley Ross, Al Narath, Dacey, Tom Cook, Everet Beckner, Orval Jones, Dick Claassen. *Background, left to right:* Sandia recruiters Marv Torneby, Howard Seltzer, Dan Arvizu.

It was Dacey's conviction as well, that regular institutional reorganization was desirable because "it stirs things and people up to put them into new patterns; it revitalizes thinking." He preferred a crisp hierarchical matrix at Sandia with two separate command chains, one supervising current activities and the other focusing on future opportunities. When Jack Howard retired as executive vice president in 1982, Dacey named two executive vice presidents, Tom Cook and Al Narath. He made Cook responsible for scheduled weapon development, energy, and test programs and Narath for long-term research, advanced weapon and component designs, and administration.

Sandia made its capabilities clear to potential customers. Thanks to SDI and the Advanced Conventional Weapons program advocated in the U.S. Senate in 1984, Sandia had more reimbursable work offered than it could accept. As Dacey remarked, Sandia was in the "catbird seat," enjoying greater demand for its services than at any other time in its history.

Sandia designed components of the W80 warhead for Tomahawk submarine-launched cruise missiles, such as this one seen in a test launch off the California coast.

A 1986 drop test of a B83 at Tonopah Test Range. Released from the B-1B bomber, the three pilot chutes pull out the bomb's main parachute for a laydown delivery.



Dick Jorgensen displays the W85 warhead designed for the Pershing II missile.

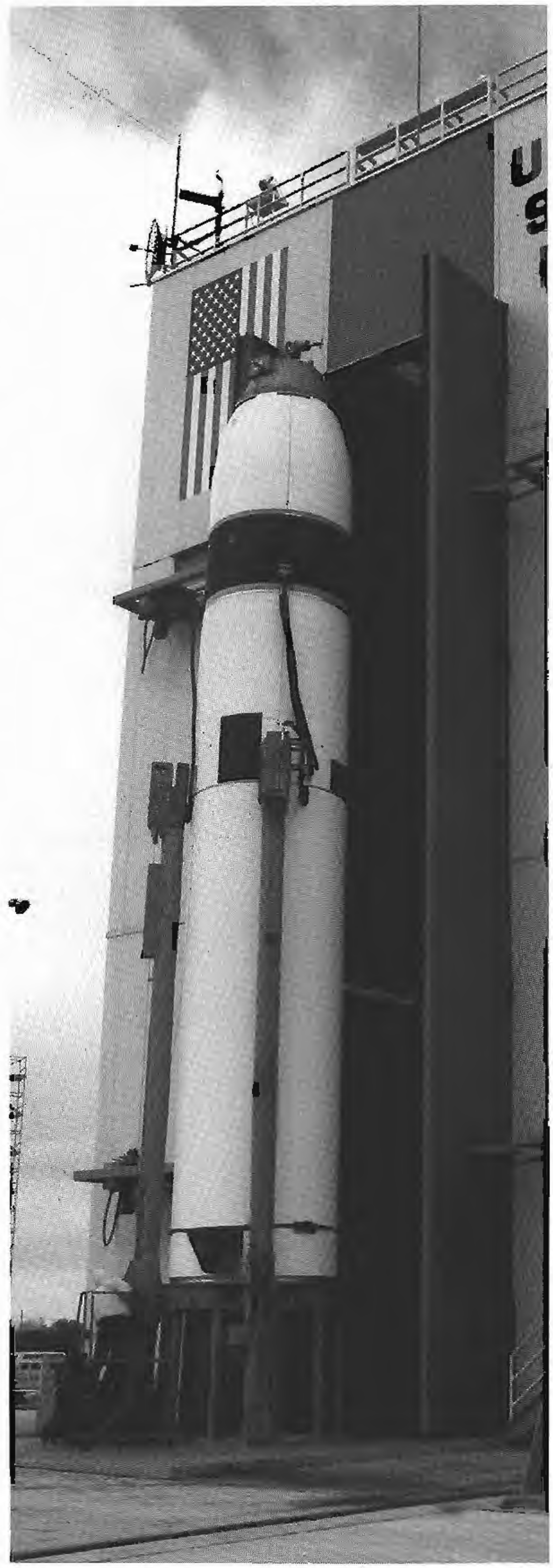
In 1987 Jim Nelsen, Joe Archuleta, Dan Luna, Harold Widdows, and Phil Owens display their B53 packed parachute system, a cluster of three 48-foot diameter parachutes in a single container.

In 1982, test flights of the Air-Launched Cruise Missile (ALCM) checked Sandia's designs for the W80-1 warhead.

TROUBLE IN WEAPON CITY

When Dacey returned to Sandia in 1981, weaponization on three major projects was nearing completion: the B83 strategic bomb, the W84 for the ground-launched cruise missile, and the W85 for the Army's Pershing II missile, and all three of these complex warhead systems moved into production by 1983. "We had not put weapons into production for a long time," said Tom Cook, adding, "Anytime you really get down to where the rubber meets the road like that, where your designs have to be produced, there is a learning curve and both we and the production complex had really forgotten the way we used to do things and we had to relearn those."

As Sandia raced to get its new weapon designs into production, problems developed, so serious that department managers, paraphrasing a popular Broadway musical, complained of "trouble in weapon city." Analyzing this situation, Dacey noted that during its early history Sandia had some responsibility for production control in the integrated contractor complex, but the



A test stand for the Navy's Trident II missile.

Sandia contributed to warhead design for the MX Peacekeeper missiles deployed in the 1980s. Here, the multiple reentry vehicles from a Peacekeeper missile create striking patterns as they return from space during a test in the Pacific.

historic trend had moved Sandia increasingly toward the early design research and development phases while transferring manufacturing engineering, process control, and quality control to the production contractors. "So the historic view — cradle-to-grave responsibility for weapons, even including their manufacture — is no longer viable," Dacey asserted. In his view, Sandians were overly concerned with problems that properly belonged to the production contractors, unless they specifically requested Sandia's help.

Two related developments supported Dacey's analysis. First, many of the Sandians who led the early weapon projects had transferred to other design areas or were retired, taking with them their many years of hard-earned knowledge and skills. To retain some of their knowledge, Dacey approved the inauguration of the oral interview and historical programs suggested by Jack Howard. He hoped also to preserve some of their knowledge in the form of computer programs — artificial intelligence, Dacey called it — but the technology needed to do that was still developing.

Second, Dacey reacted to the fact that Sandia's staffing had remained relatively constant for years, while the number of people assigned to weapons development had declined by twenty percent. Sandia therefore bolstered weapon programs staffing through transfers from the declining energy programs and from the W82 program for the 155-millimeter artillery shell, which Congress canceled in 1983 only to restart it in 1985 before ending it completely in 1990.

Although Sandia's managers were initially uncertain that the production schedules for the three major weapons, plus the versatile W80 for cruise missiles, could be met, strenuous efforts brought success. At the end of 1983, Dacey proudly announced on-time completion of all schedules, an extraordinary achievement with significant political implications. "A major factor in arms control negotiation," Dacey commented, "was our ability to demonstrate that NATO meant business."

Even as these weapons entered production, the Reagan administration's defense emphasis brought impetus to new warhead development projects, notably one for the Air Force MX or Peacekeeper missile (W87) and another for the Navy's Trident II missile (W88).

Wanting a mobile intercontinental ballistic missile to thwart the threat of a Soviet preemptive first strike against the existing Minuteman missile silos, the Air Force initiated studies of advanced ballistic reentry vehicles, later renamed the MX, and finally, Peacekeeper, during the 1970s. "Smart" fuzing systems studies were initiated in the mid-1970s in Dan Hardin's advanced

A 1987 test of a Peacekeeper missile at Vandenberg Air Force Base, California. A gas generator ejected the missile from the silo before its rocket ignited.

During the 1980s, George Dacey and General Ken Withers of DOE presented Weapons Recognition of Excellence Awards to Sandians. This was the 1985 ceremony at Albuquerque. *Left to right:* Dacey, Withers, Bill Stevens, Bob Luna, Paul Longmire, Steve Burchett, Gordon Boettcher.

fuzing division for this system and the Trident II. New concepts included a radar-updated path length fuze based on an accurate radiation-hardened crystal clock and a stabilized force balance integrating accelerometer. These studies were supported by both DoD and DOE funding.

Amidst a national debate over survivable basing modes, Sandia developed subsystems for the W78 warhead designed both to replace the three W62s carried by Minuteman missiles and for the Peacekeeper missiles as well. Roy Fitzgerald and Heinz Schmitt, followed by Bill Ulrich, managed Sandia's electrical and mechanical designs for the W78.

After production of the W78 began in 1979, Sandia proposed design modifications of the W78 hardware to fit requirements for the Peacekeeper missile. These proposals initially included integrated arming, fuzing, and firing systems, incorporating the "advanced smart fuzing" concepts being explored by Hardin's group for both the Air Force (Peacekeeper) and Navy (Trident II) missiles. In 1982, however, the Air Force elected to develop an entirely new warhead, the W87, specifically for the ten-warhead Peacekeeper missile.

In 1982, Bob Peurifoy's directorate drafted a proposal to the Air Force for Sandia development of the complete reentry arming, fuzing, and firing system, and Sandia staffed a fuze development department headed by Hardin for this large potential reimbursable program. Under this arrangement, Sandia staff at Livermore under Jay Gilson would provide W87 warhead design, including the electrical system, neutron generators, structural design, and a new gas transfer system while the fuzing development department in Albuquerque would provide the reimbursable arming and fuzing design.

Proceeding with Sandia's customary weaponization at Livermore, Sandia's W87 design program had project divisions headed by Cliff Yokomizo, Paul Heppner, and Hank Witek, with Dave Dean and Doug Henson as lead engineers, and under the overall program leadership of Gilson. Use of computer design analysis marked the work on the W87. By 1980, Sandia had acquired roughly $50 million worth of centralized computers, including its first Cray supercomputer, twenty times faster than earlier computers, which allowed the solution of previously intractable analytic problems. To ensure hardness against countermeasures and predict component shock response in the

W87, the project team developed computational techniques and formulated analytical models with aid of the Cray and then verified the models through field tests.

On a close schedule, Sandia deployed a prototype system for the first Peacekeeper flight test in 1983 and maintained a schedule to permit deployment of the first Peacekeeper missiles in late 1986. In retrospect, it was, said George Dacey, a very "solid program."

However, Sandia suffered a disappointment in its proposal for developing the Peacekeeper's arming and fuzing system. In 1983, nine months into a phase 3 design, the Air Force elected to use its traditional aerospace fuzing contractor for the W87 fuze.

Sandia fuzing efforts were then concentrated on the Navy's Trident II (Mk 5) reentry body. In 1983, Sandia signed its third reimbursable agreement with the Navy's Strategic Systems Programs office for an integrated arming, fuzing, and firing assembly. After outstanding performance during the Poseidon project (Mk 3) of the 1960s and Trident I project (Mk 4) of the 1970s, Sandia became a natural choice to work with the Navy and Lockheed in 1983 on a system for the formidable Trident II missiles. Carried aboard Ohio-class submarines, the Trident II D-5 missile would

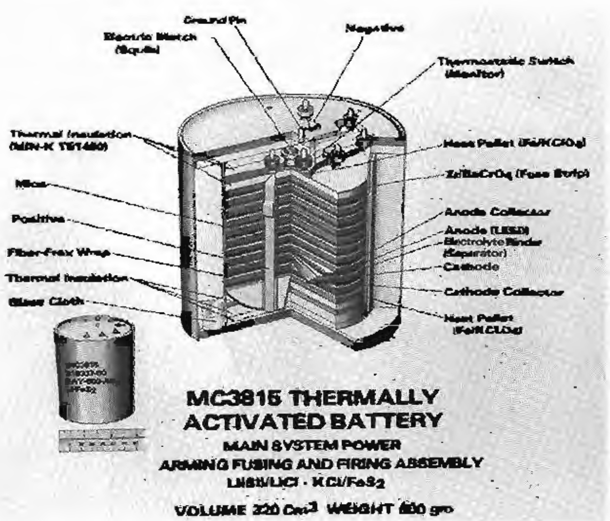


Diagram of a thermal battery in 1986 similar to those used in Sandia's design for the Trident II. Thermal batteries contain no liquid and have long shelf lives.

In 1986, Gordon Boettcher holds two rugged, radiation-hardened Sprytrons he invented as switches for use in weapons.

provide a powerful anchor for the national deterrent triad.

For the Trident II (Mark 5 reentry body), the Trident development department coordinated studies with the Lockheed Missile and Space Corporation to develop a new fuze that included a radar-updated, path-length compensating fuze, as developed earlier by Hardin's advance fuzing division, that could adjust for trajectory errors and significantly improve the ability to destroy a target. This was an early and sophisticated use of artificial intelligence in a weapon. Also included was a radar proximity fuze of exceptional capability.

Hardin was named program manager for the entire W88 Trident development program when development was authorized by the Navy in 1983. Within the Trident development department, Sam Jeffers headed warhead development, John Duncan was responsible for testing, Ron Hartwig headed the analysis division, and Bill Nickell headed the arming, fuzing, and firing division. The Trident II warhead system employed a new wireless fireset, slapper detonators, uniquely coded arming signals, reduced-size neutron generators, a long-life thermal battery, and a radiation-hardened data multiplexer for processing instrumentation data during both flight and underground testing. The radar-updated path length fuze required the development of long-life thermal batteries.

Also critical to the design of this football-sized fuzing system were new low-power integrated circuits using radiation-hard complementary metal oxide semiconductor (CMOS) technology and metal nitride oxide semiconductor (MNOS) memory chips developed at Sandia. The Trident II arming, fuzing, and firing system epitomized Sandia's miniaturization and radiation-hardened microelectronics capabilities.

The Trident II schedule required Sandia to produce the first package assembly unit in late 1985, be ready for the first flight test in 1987, and begin full production by 1988. To meet these milestones and to provide the requisite protection against hostile radiation, Sandia itself produced the custom-made large-scale integrated circuits for the warhead package in a new facility named the Center for Radiation-hardened Microelectronics.

BY JUPITER

"We had to do it internally if we were going to get it done at all," said Dacey in 1983, explaining why Sandia custom-made the semiconductors. The meager market for radiation-hardened electronics did not entice industry to provide them, and in some cases the use of classified weapon devices raised security concerns. Gene Reed and Bob Gregory, and later John Galt, Larry Anderson and Harry Saxton, formed and managed Sandia's Center for Radiation-hardened Microelectronics (CRM) in the 1980s to produce microelectronics for Sandia's use in weapon systems as well as for Defense satellites and NASA space probes. The CRM's principal product consisted of large-scale integrated circuits containing up to 100,000 transistors on each silicon wafer.

Specifically, the CRM produced CMOS circuits, hardened against radiation, and needing little power for high performance. Related, and extraordinarily challenging, production involved MNOS for hardened non-volatile memories. By achieving radiation hardening through careful design and selected process sequences carried out in the sterile environment of clean rooms, Sandia provided integrated circuits that permitted miniaturization of many weapon system components, including the Trident II.

Sandia produced about 12,000 radiation-hardened microprocessors and custom integrated circuits like this half-inch square silicon-gate memory for NASA's use in the Galileo space probe. These reached the planet Jupiter in 1995.

Sandia's radiation-hardened microelectronics also found application in the GPS and DSP satellites launched in the 1980s to operate in the Van Allen radiation belt ringing the earth. Sandia provided optical detectors and instrumentation for these satellites, including computer microprocessors to handle all power commands, timing, and sensor data. The CRM furnished the special radiation-hardened microprocessors and memories to assure proper functioning in the Van Allen belt.

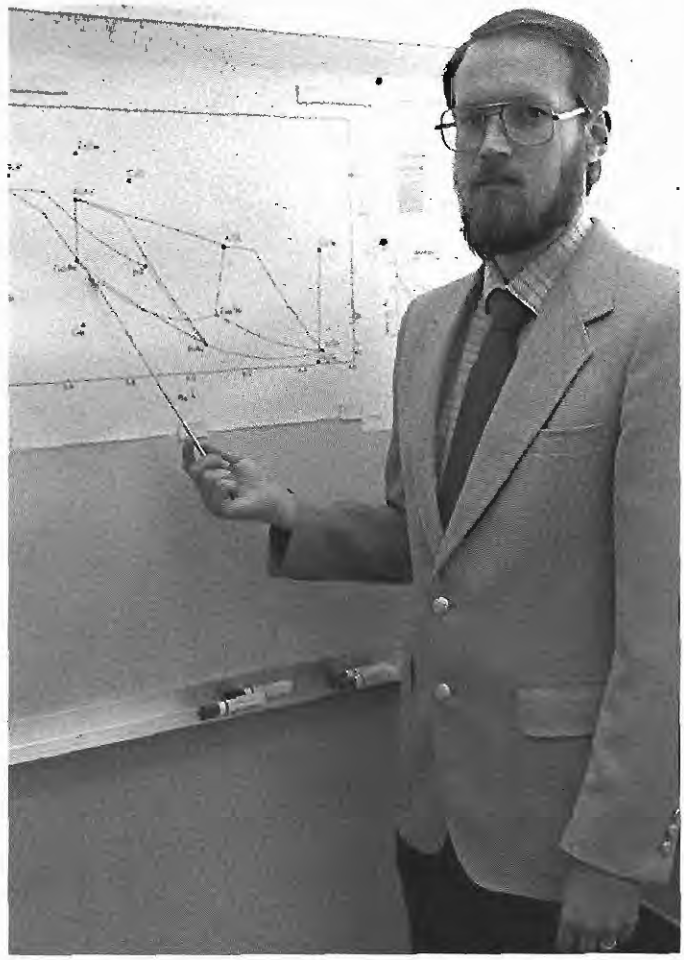
Because NASA planned to dispatch the Project Galileo space probe to the planet Jupiter during the 1980s, it requested Sandia to supply the circuits, microprocessors, and memories needed to operate in the intense Jovian radiation. For Galileo, Sandia's CRM produced 12,000 hardened microelectronics components. Launched toward the giant planet during the late 1980s, Galileo arrived at its Jupiter orbit in 1995, then sent a probe into the Jovian atmosphere to return new information on that disturbed planet, wracked by comet impacts in 1994.

Above: Sandia technicians at work in 1981 in the Semiconductor Development Laboratory.

Right: Elaine Buck, uniformed for work in a clean room, holds a semiconductor wafer made at Sandia.

Below: Sandia technicians in a corridor of the Microelectronics Development Laboratory, formerly the Center for Radiation-hardened Microelectronics, are dressed to work in laminar-flow clean rooms for processing semiconductor wafers.

Out of Sandia's research on semiconductors and microelectronics came a revolutionary concept for which Sandian Gordon Osbourn received the prestigious DOE Lawrence award in 1985. Osbourn conceived the theory of the strained-layer superlattice (SLS), semiconductors made of alternating layers of crystalline materials, placed by the molecular-beam epitaxy process in layers so thin that the atoms aligned easily by elastic strain. Briefly, this discovery made it possible to tailor specialized, tunable semiconductors to suit their functions. Calling the SLS concept excellent and exciting science, Dacey pointed out that it "changes the properties of the material and thus may enable the design of devices very different in their basic parameters from others in the past."

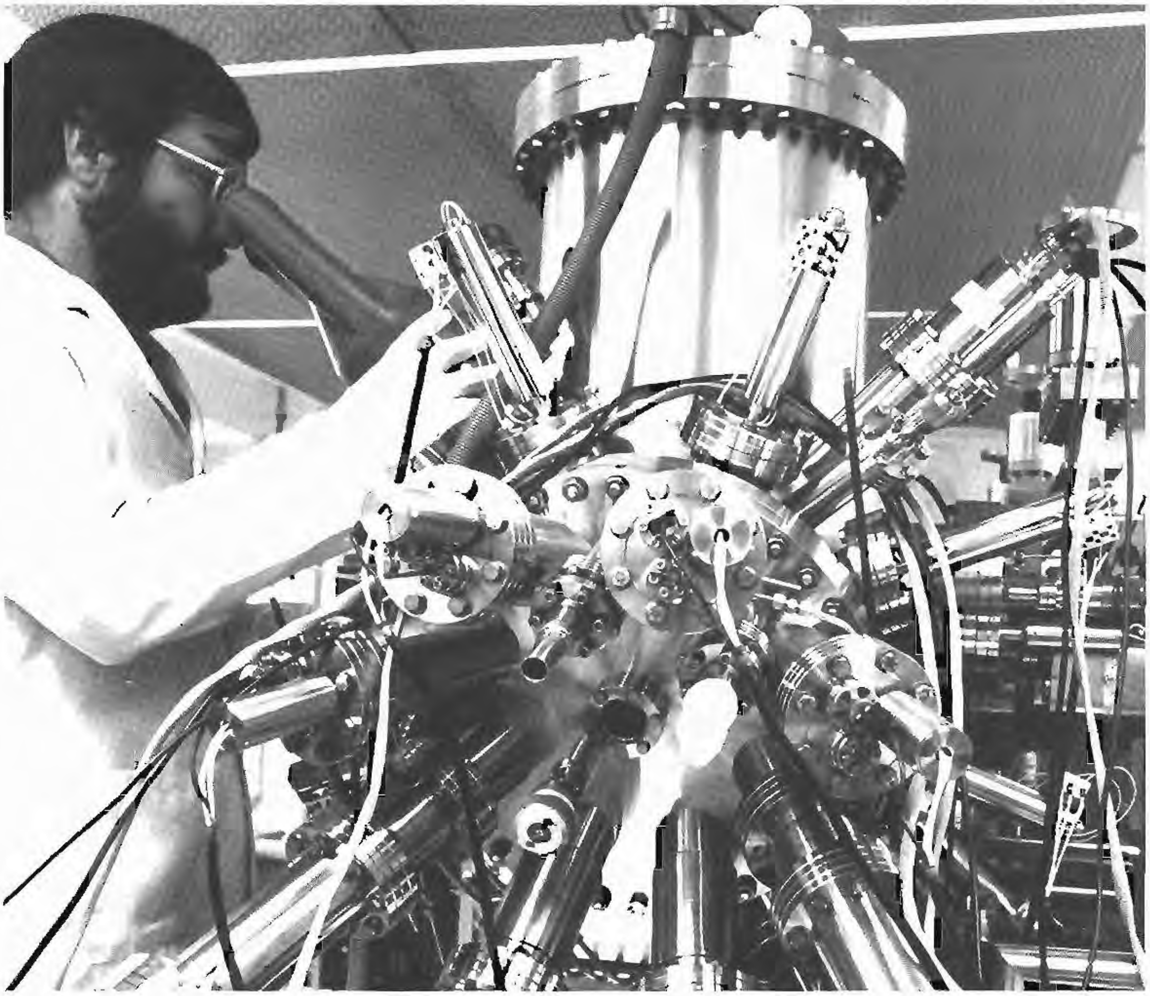


In 1985, Gordon Osbourn was one of six scientists to receive the Department of Energy's Ernest Orlando Lawrence Memorial Award for outstanding contributions in the field of atomic energy. Gordon was cited for his work on strained-layer superlattice theory.

During the 1980s, Sandia experimented with SLS materials to produce tiny diode lasers and photodetectors. For weapons applications, the SLS devices found application in the design of advanced radar fuzes, as well as in fiber optics and photonics. SLS research indicated that tailoring custom-made devices layer by atomic layer might in time make possible highly efficient solar cells, high-speed transistors, and tunable light-emitting diodes operating at specific wave lengths.

As an analogy for Sandia's research in semiconductors, Dacey enjoyed relating a story told to him by Don Shuster about bumblebees. Examination of a bumblebee's brain indicated it had active elements little more complex than those of a supercomputer chip. Yet, with only a rudimentary intelligence the bee could distinguish between flowers and thistles while performing complex maneuvers in the air. "Our weapons, our radars," Dacey lamented, "can't tell the difference between a truck and a tank, much less between a Russian tank and an American tank." With improved sensors and semiconductor computers in weapons, Dacey speculated, perhaps they could begin to rival the intelligence of a bumblebee.

Dacey supported the creation of Sandia's Radiation-hardened Integrated Circuits Laboratory during the early 1980s, because it would be able to produce circuits another order of magnitude more complex than what could be produced at the CRM. "Sandia is on the threshold of real progress in integrating sensory information into an understanding of state and action to modify that state through the use of visual information, pattern recognition, motional information, positional information, and other kinds of sensory data," said Dacey, ruminating on the implications of advances in chip design. "If we succeed, we'll have a machine able to react to its environment in ways comparable, in a small way, to what people can do. That would clearly have immense military application."



Raymond Hibray works at a molecular beam epitaxy machine used for crystal growing and building strained-layer superlattices layer by atomic layer.

TECHNOLOGICAL MAYPOLE

Observing in 1984 that the "day of gravity-dropped bombs is about gone," Dacey pointed to the Sandia winged energetic reentry vehicle (SWERVE) as an exploratory project of great promise. "Going from ballistic weapons to intelligent, maneuverable, controllable weapons has got to be a step in the right direction," Dacey expanded, describing SWERVE as a technological maypole around which Sandia concentrated its developing technologies.

In typical missions, the SWERVE weapon would be rocket launched on a ballistic trajectory toward the target and guided by an inertial navigation system. As it reentered the atmosphere, it would level off at high altitude to cruise at hypersonic speed toward the target. A miniature, on-board radar would precisely measure the distance and angles to a known reference point near the target, and this data would update the navigation system to eliminate drift errors accumulating during flight. SWERVE could then maneuver to the target, delivering a kinetic-energy warhead that would destroy the target through collision, not explosion. SWERVE and its kinetic-energy warhead would provide a "cookie-cutter" effect, highly lethal in the target area but not outside it. In brief, a building on one side of a street could be destroyed while those across the street remained intact.

Supported in part by funding from the Defense department, SWERVE was developed in Bob Clem's exploratory group under the

Sandia test engineers at the Kauai Pacific Missile Range prepare a Sandia-developed Strypi rocket in 1980 for the launch of SWERVE II, a maneuverable reentry vehicle.

management of Don Rigali. As a possible countermeasure against threats from Warsaw Pact tactical missiles, Sandia developed SWERVE for controlled maneuvers and quick retaliatory response. After a test launch aboard a Strypi rocket at Kauai in 1980, a SWERVE prototype reentered the atmosphere, leveled at 25,000 feet, then maneuvered to target as planned. Rigali explained that it could travel a thousand miles in fifteen minutes, much faster than cruise missiles, to destroy moving targets.

With a protective carbon nosetip and surface coating, SWERVE could survive reentry heating and maneuvers at hypersonic speeds. It had cruciform wings and movable control surfaces (elevons) for maneuvering, and guidance provided by Sandia's first multiprocessor flight computer, first fully digital autopilot, first angle-of-attack control system, and first navigation system that greatly surpassed ballistic accuracy. Successful testing of SWERVE continued through the 1980s, demonstrating its ability to use its flight control surfaces to glide along the upper atmosphere and greatly extend the launching rocket's range and impact "footprint."

The brain for SWERVE was the Sandia airborne computer (SANDAC), packing the power of a mainframe computer into boxes that shrank with each new model, down to the size of a cereal box. Before the applications of microprocessors to nuclear weapons during the 1970s, Sandia used hard logic — transistors or low-level gates on small-scale integrated circuits. These provided

The Sandia Airborne Computer (SANDAC) became the brain of SWERVE. The fifth version of SANDAC shown here packed supercomputer power into a six-inch box.

little flexibility. If a change in functions was required, it was necessary to rebuild the logic boards. The advent of microprocessors added flexibility by accommodating changes simply by changing the software. Packed with advanced microprocessors, SANDAC was first used in Sandia's TIGER program of the 1970s, described in an earlier chapter.

Developed largely under the management of Jack Wirth, Ed Barsis, Charlie Blaine, and associates, SANDAC concentrated the power of a very-high-speed, parallel-process computer capable of carrying out millions of instructions per second into a modular package. At the recommendation of research vice president Bill Brinkman, Dacey in 1985 established a computer science directorate to pursue further development of SANDAC, aiming ultimately to put the entire system on a single microchip.

In the late 1980s, the SWERVE project merged into the Defense department's hypersonic weapon technology program, exploring the development of a missile capable of traveling at Mach 5 or faster. This new approach to air defense differed radically from existing systems. An air-launched rocket would carry an interceptor to the upper atmosphere, then the interceptor would race toward its target, gliding along the upper atmosphere like SWERVE, to its destination, where it would dive at the target with radar and infrared sensors guiding its final approach. Such maneuverable hypersonic interceptors posed many technical challenges: at hypersonic speeds, for example, improperly designed or fabricated flight-control surfaces can burn off. Sandia became responsible for designing test vehicles able to meet such challenges.

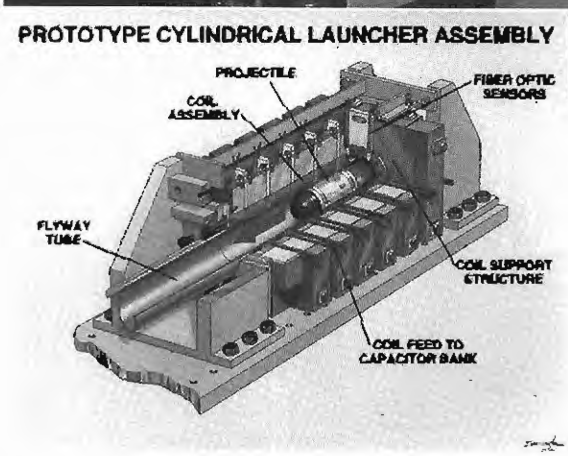
Sandia also built on its communications and sensor capabilities for contributions to the ongoing Modular Building-Block (MBB) program. Many branches of the Department of Defense required command, control, communications, and intelligence systems for use in the field. However, not all users required the same capabilities. Furthermore, it was not uncommon for acquisitions to take ten years from conception to initial operational ability and the resulting systems were often outdated before they were used. In recognition of this, in 1983 the Defense Communications Agency (DCA) sponsored a study of technology solutions for both acquiring and retrofitting systems. Sandia and the MITRE Corporation, along with several contractors and consultants, worked with DCA and proposed the MBB concept. In this concept the system interfaces are standardized and components are packaged to be reliable, sturdy, environmentally-hardened, and suitable for a variety of users. Much like commercially available computer software, components that meet a particular user's needs can be plugged into a central architecture that multiplexes all data and control signals for the system. The resulting system is based on a central data bus and appropriate off-the-shelf components. Subsystems are assembled with simplified wiring into rugged, portable trailers with multi-level security and a single-operator remote control capability. Sandia's effort was led by Tom Sellers, Mike Eaton, and Ron Glaser, whose application of the system engineering approach and flexible project management contributed to the system's success and resulted in considerable savings in time and money for DoD.

BLUE RIBBON TASK GROUP

In 1984, Senators Sam Nunn and John Warner proposed moving budgeting for nuclear weapon production to DoD, with DOE performing its customary design, development, and production activities on a reimbursable basis. The Senators expected this to impose better cost discipline on warhead procurement. Senator Pete Domenici, however, proposed study of these issues, and Congress established a blue ribbon task group to review nuclear weapon programs and recommend improvements. Managed by Judge William Clark, who was assisted by Sandian-on-leave Ted Gold, this study in effect was an update of the 1975 Transfer Study and the 1980 Starbird Study.

When it completed its investigations in 1985, the group endorsed the existing dual agency system of program management and recommended continuation of the dual

Ronald Kaye inserts a 5.5-inch projectile into a prototype electromagnetic launcher. Sandia studied this technology for use in launching small payloads into space, or as magnetic artillery.



agency judgment process. It also recommended that DOE's nuclear weapon safety, security, and use control expertise be applied to advanced conventional weapons. Visiting Sandia, Presidential science advisor George Keyworth predicted that defense would soon shift to a more balanced deterrent based upon both nuclear and conventional weapons. "A place like Sandia," Keyworth remarked, "must consider the role it might play as a defense lab, not only as a nuclear weapons lab."

With this added impetus, the Defense and Energy departments signed a memorandum of understanding (MOU) in 1985 providing that DOE's laboratories would apply their expertise to improving conventional weapons technology on a reimbursable basis. The first year, DoD committed $5 million, matched by DOE, to initiate the program. This amount was equally split among Sandia, Los Alamos, and Lawrence Livermore laboratories and was supplemented with funding contributed by the armed services for specific projects. Leadership at Sandia for its venture into advanced conventional munitions programs came from the staff of Bob Clem's exploratory group including Max Newsom, Tom Hitchcock, and Bill Tucker.

Early conventional weapon projects performed by Sandia included development for the Air Force of a penetrating bomb, of rocket propellants, and of warhead fuzes. Working with the Air Force Armaments Laboratory, Sandia assisted in the development of a 2,000-pound bomb with a structural casing able to penetrate hard targets. A Sandia team also developed a high-G telemetry package that fit into a 155-millimeter shell for firing through twelve-inch-thick concrete walls. "It is the first time anyone had measured the internal environment as a shell penetrated these structures," said Newsom. "Providing data essential to develop fuzes that detonate at the proper location." In addition Sandia re-explored fuel-air explosives, like Pave Pat, for use against blast-sensitive targets.

The DOE-DoD MOU program sought to resolve problems common to both nuclear and conventional weapons. These included integration of sensors and data analysis to find targets, delivering weapons with greater precision, and destroying targets. This required studies of shock waves, materials, structures, and computer codes to analyze the systems. "We're putting thought into the possibility that you can remove people from the battle zone, but still be in control of the weapons," said Clem. It was this possibility that Everet Beckner and Jim Banas had in mind when they initiated Sandia's robotics research during the mid-1980s. Studies of remote-controlled robotic vehicles that could destroy tanks, replace human forward observers, or clear mine fields were soon underway.

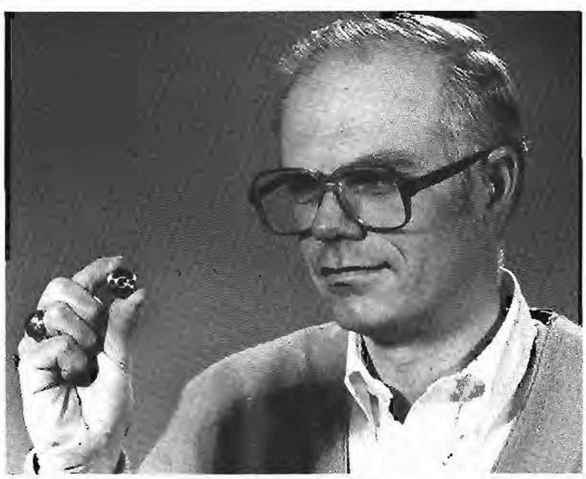
As nuclear arms control negotiations proceeded, the issue of how to deal with Soviet superiority in conventional armor without nuclear weapons arose. For anti-tank weapons, Sandia offered electronic safing and arming devices coupled with advanced detonators for the fuzing of armor-piercing conventional munitions and the firing of insensitive high explosives. It conducted studies of radically new armor-penetrating weapons for use against tanks or ships, and Newsom bluntly announced, "We have developed the technology to penetrate just about any manmade structure."

This technology included Sandia's experiments with tandem warheads and magnetic artillery as anti-armor weapons. Tandem warheads fired first when they hit a target to drive a rod through armor before a following second rod struck the same spot to enter into a vehicle interior. An outgrowth of Sandia's studies of launching small rockets with electromagnetic force, magnetic artillery (induction coilguns) potentially could fire shells farther and faster than conventional explosives. Their speed and penetration power might well prove useful against armored vehicles.

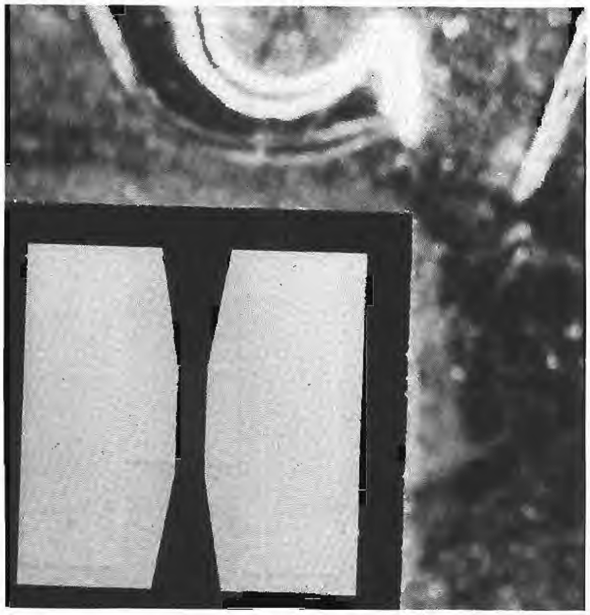
Unlike other armed services, the Marine Corps had no specific laboratory serving its needs, and it therefore called for Sandia's technological support. In 1985, the Corps requested development of a lightweight battlefield sensor with greater capabilities than the system Sandia rushed into production in 1965 for use in Vietnam. Sandia designed a new lightweight sensor system that could detect the passage of troops and vehicles, then produce reports showing the direction and type of traffic, as well as its time of arrival at the next sensor location. Moreover, the system could be monitored on personal computers by combat troops.

When the Army Missile Command developed a guided weapon for use against helicopters and armored vehicles, it requested that Sandia provide the safing and arming device. Drawing on its mature nuclear weapon fuzing technology, Sandia's safing and arming design replaced mechanical components with a slapper detonator and an all-electronic design, also adding insensitive high explosive and disarming features for increased safety. This became the first all-electronic safing and arming system adopted by the services for conventional weapons.

Sandia used slapper detonators, or exploding foil initiators, to trigger explosives because they required large and fast power pulses for operation, decreasing the risk of inadvertent detonation. The slappers made the safing, arming, and firing functions for a weapon entirely electronic. Moreover, Sandia invented the semiconductor bridge to replace the hotwire detonators commonly used to activate explosives.



Bob Bickes, an inventor of the semiconductor bridge for igniting explosives, holds one in his hand. Actually, the semiconductor bridge is so small that it is not visible. It is inside the center hole in the ring-size ceramic explosive powder.



Developed at Sandia during the 1980s, this semiconductor bridge can ignite explosions 1,000 times faster than earlier igniters. In this picture, the tiny semiconductor bridge sits atop a penny, with the bottom of the C in the word CENT partly visible.

Bob Bickes and Al Schwarz in Sandia's pyrotechnics group developed the semiconductor bridge capable of igniting explosives a thousand times faster than conventional hotwire detonators. A hotwire heated by electricity to 1200 degrees ignites explosive powders pressed against it to trigger an explosion in thousandths of a second. By contrast, a semiconductor bridge has a crossbar doped with phosphorus; a tiny electric pulse turns the doped area into a plasma, a superhot ionized gas, causing an explosion in millionths of a second. These microminiature semiconductor bridges require little power, are insensitive to static electricity, and can be coupled to digital circuits for precise timing. Bickes declared that the bridges could be used to initiate quick course corrections for missiles, and David Anderson predicted the bridge would eventually be used to set off air bags, fracture rock, or ignite fireworks displays. A decade after their introduction, the semiconductor bridges did, indeed, find such commercial applications.

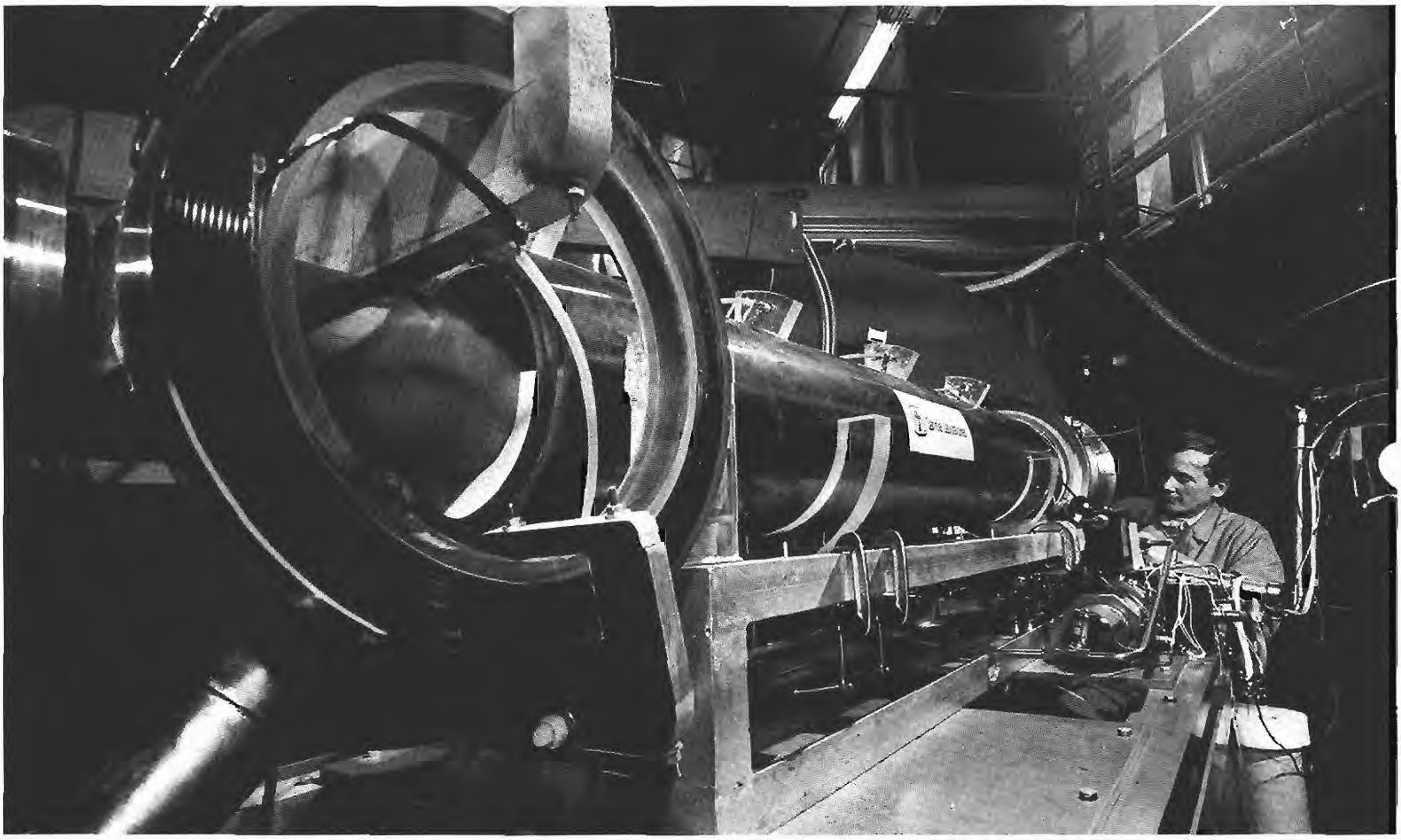
Sandia soon had more conventional weapons and reimbursable proposals than it could accept. "If we start something new, we have to cut something else out," lamented Max Newsom.

STAR WARS

Another large reimbursable program for Sandia began in 1983 when President Reagan called for development of defensive systems that might eliminate the threat of nuclear attack on the United States. "Would it not be better to save lives than to avenge them?" the President asked. Because the Strategic Defense Initiative (SDI) proposed defending the United States from space, perhaps with lasers or directed-energy beams to knock down nuclear-armed missiles, critics dubbed his initiative "Star Wars" after the popular science-fiction films. George Dacey reacted enthusiastically to the President's initiative. "The perception is growing throughout the world that nuclear weapons alone are not suitable for ensuring world peace," he said. "Alternatives must be sought."

The United States had not seriously addressed self-defense as a policy option since signing the 1972 Anti-Ballistic Missile treaty and dismantling the Sprint and Spartan missiles of the Safeguard system. Instead, national policy relied upon the deterrent threat of mutually assured destruction by offensive weapons to maintain a balance of power. The President's approval of a new defensive space-based system therefore constituted a revolutionary policy change that critics feared would alter the balance of power.

Bob Clem and Gerold Yonas served on the panel reviewing the Strategic Defense Initiative.



A large hydrogen-fluoride laser built and tested at Sandia.

Space seemed an ideal region for defense because light, radar, x-rays, and other bands of the electromagnetic spectrum travel freely over great distances in its vacuum, above atmospheric interference. Indeed, even small pellets or shrapnel could fly through space unimpeded, posing deadly threats to satellites or incoming missiles. If orbiting platforms carrying power sources and lasers could be stationed in space, they might be able to destroy missiles rising from their launch pads and crossing through space on their way to targets in the United States. These were exciting and challenging scientific and technical concepts.

Soon after his announcement, the President ordered the formation of study groups to plan strategic defense research, and Sandians Bob Clem, Gerold Yonas, and Glen Brandvold received assignments to the study group chaired by James Fletcher of NASA. During the summer of 1983, they surveyed the broad range of approaches to strategic defense in order to narrow the focus to the most promising concepts.

Clem and Brandvold worked on the team analyzing likely Soviet countermeasures to the defense schemes, becoming in effect the "red team." Yonas, heading the team examining directed energy weapons, said later, "The members of the Red Team had the audacity to propose to simply shoot us out of the sky. That's when we all got very serious about the survival probabilities of the defensive technologies we were proposing."

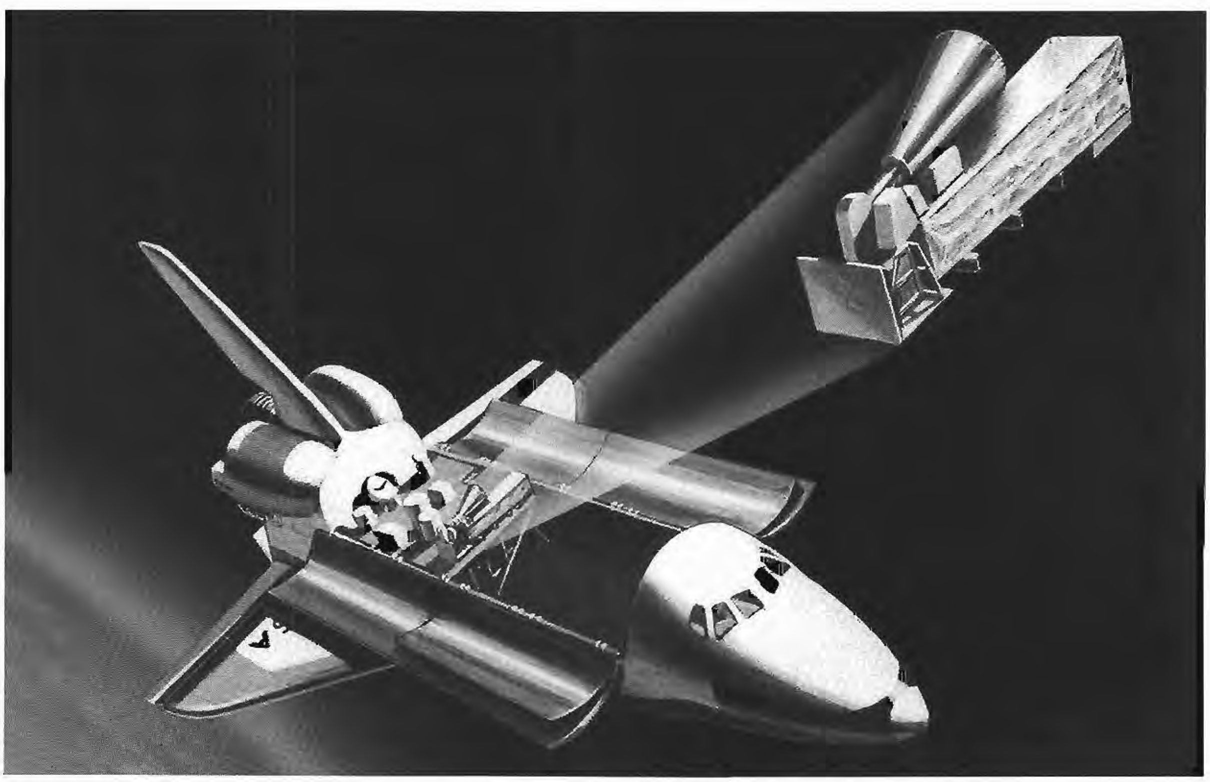
When Clem pointed out that creating a strategic defense system seemed as technically formidable as the race to the moon in the 1960s, Yonas responded that it was even more ambitious. "At least when the lunar module was landing, the moon didn't shoot back. And it didn't shift position, or turn out to be green cheese — or quicksand." When the Secretary of Defense in 1984 formed the Strategic Defense Initiative Office (SDIO) headed by James Abrahamson, Yonas was loaned to SDIO as Abrahamson's chief scientist.

Although Sandia achieved many technical advances in support of strategic defense programs, the staff involved in the program later expressed greatest pride in their service as the Red Team, claiming that their analyses saved the taxpayers millions. However, Don Rigali, who managed the Red Team experiments later admitted, "Parents don't always like it when you say their kids are ugly."

There were a dozen proposed concepts for nuclear-driven beam weapons when Sandia began its studies. Using its established expertise in the survivability of nuclear weapons, Sandia identified the most promising directed-energy concepts, enabling SDIO to shift its resources to the concepts with the greatest potential. "As a result of our work in nuclear weapons, which would have to survive a Soviet version of SDI, we are natural players in the countermeasures game," summarized George Dacey. "We do want to look at all the possible ways in which a potential SDI system could be defeated, because, after all, we may be in the position of having to defeat a Soviet SDI system with our weapons."

DIRECTED-ENERGY WEAPONS

The media focused its attention on the potential use of particle accelerators as directed-energy weapons, dubbing them the "death rays" envisaged in science fiction stories and films. Lightning strokes provide visible particle acceleration and, indeed, when a static electrical spark passes from a finger to a metal object, the human body becomes one electrode in a natural accelerator. Accelerators created by modern technology ranged from the picture tube in a television set to the fifty-two-mile long superconducting supercollider that was under construction in Texas before Congress canceled the project. Sandia had



A 1986 plan for launching directed energy weapons from the space shuttle.

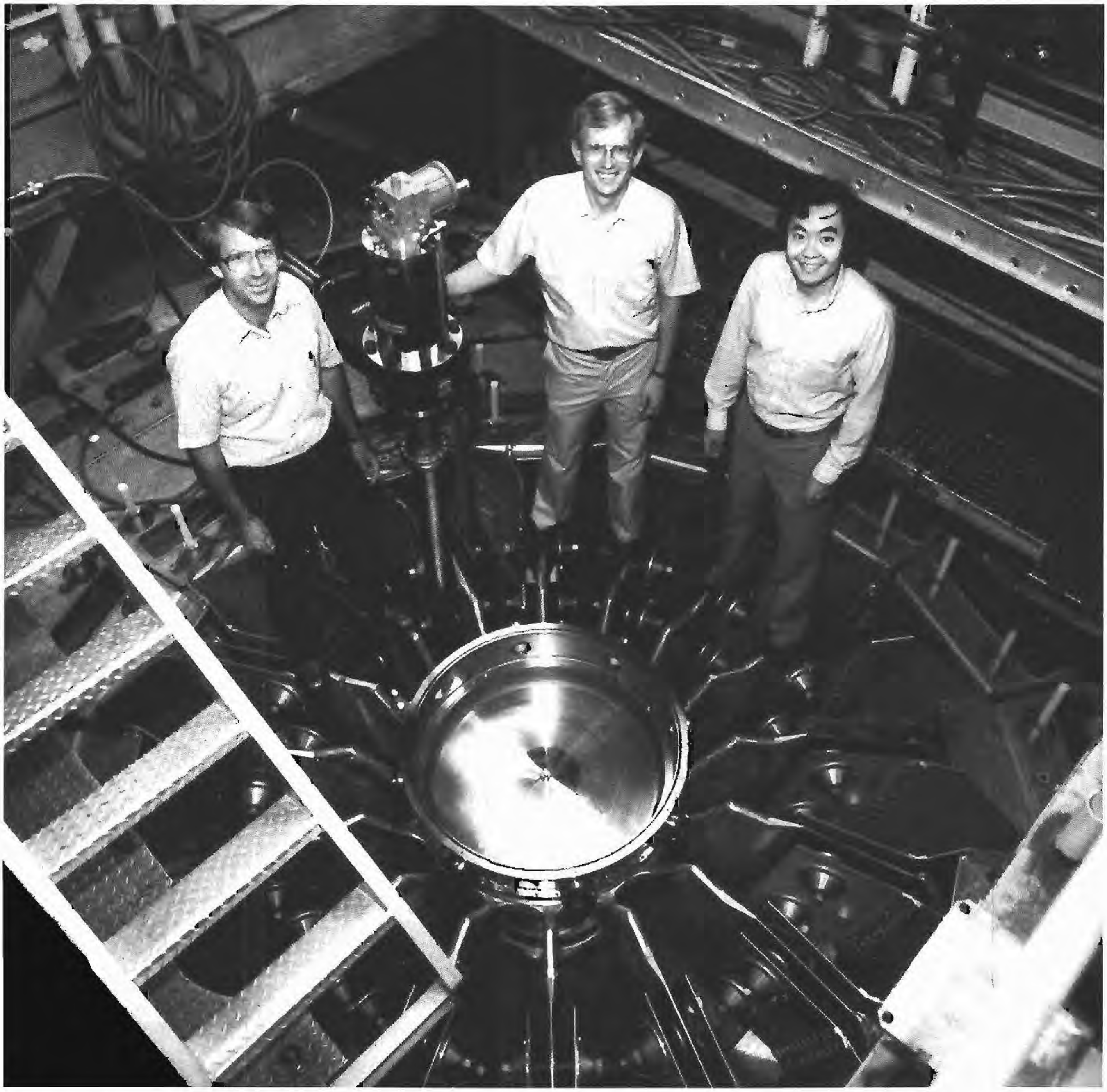
SDIO director General James Abrahamson tours Sandia's SDI projects. *Left to right:* Roger Hagengruber, Orval Jones, Abrahamson, Venky Narayanamurti.

used particle accelerators for scientific and weapon effects research since the 1950s, and by the 1980s its pulsed-power sciences had achieved national recognition for research on weapon effects and inertial confinement fusion (ICF). This expertise became important to developing SDI concepts.

Early in the SDI program, the media generated considerable excitement about the potential of a nuclear-weapon-pumped x-ray laser, a concept popularized by Edward Teller and known as Excalibur. During the early 1980s, Rick Wayne and Rob Rinne, while studying microwave effects on weapons, learned of the x-ray laser studies at Lawrence Livermore and began examining how Sandia might complement this research. After Reagan's proclamation, Wayne's group left its microwave-hardening research to focus on directed-energy weapons, and Wayne became Sandia's coordinator for SDI research.

As part of its x-ray laser research program, Sandia used its Proto II accelerator (a prototype for its ICF machines) to evaluate imploding plasmas. "It is extremely difficult to make an x-ray laser," reported Keith Matzen, manager of the experiments. "You have to have a large [high] energy-density source of photons to energize the laser, and the timing between the pump source and the laser medium has to be very precise." The imploding plasma would become Sandia's most powerful x-ray source. In its traditional role as ordnance engineer for the designs produced at Lawrence Livermore and Los Alamos, Sandia supported both in their SDI research and testing. For the x-ray laser concept, Sandia studied its potential role as a missile interceptor to be deployed on submarines and launched into space when needed. This research soon revealed the need for earlier detection of missile launches and for a means of distinguishing between real warheads and decoys. Soon, Sandia teams engaged in studies of the technology required to meet both these needs.

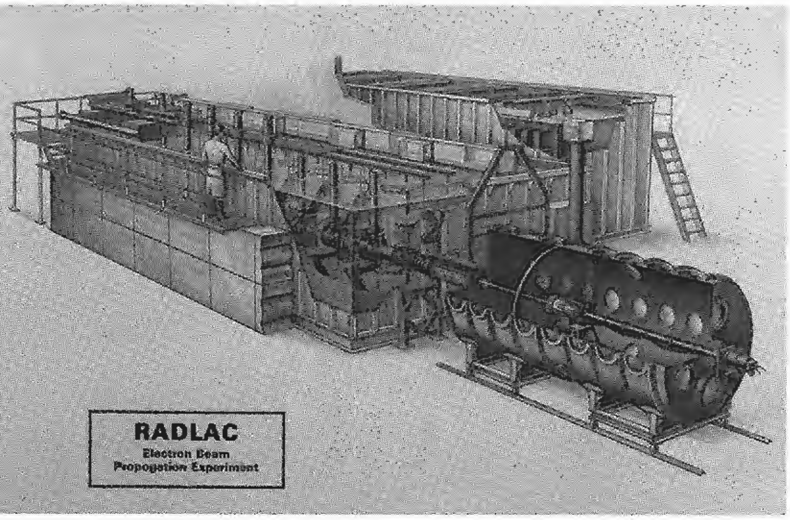
Much of the early SDI program at Sandia stemmed from the Labs' growing capabilities in pulsed power sciences and machines, developed initially for simulation of weapon effects and later for experiments with ICF. It transferred this expertise into the development of linear particle accelerators that might eventually become directed-energy weapons. Notable was its collaboration with Phillips Laboratory (then the Air Force Weapons Laboratory) in developing RADLAC, a radial pulse linear accelerator.



Standing atop the diode of Proto II, where x-ray laser experiments were performed for SDI in 1984, are Keith Matzen, Rick Spielman, and Warren Hsing.

In 1979, Soviet physicist A. I. Pavlovskii revealed his research into using pulsed power for electron-beam propagation, creating interest at Sandia and in the Defense department. The Navy might use such a weapon to defend ships against missiles, and the Air Force could use it to defend missile silos.

Sandia and Phillips Laboratory initiated joint investigations of electron-beam propagation. In these large accelerators, as in other pulsed power systems, electricity was stored in a bank of capacitors over a time period, then discharged all at once in a high energy pulse. "This is somewhat like a multistage rocket," explained Ken Prestwich, "where the space capsule's velocity



Schematic diagram of the RADLAC electron beam propagation experiment at Sandia.

is increased by sequential firing of the multiple rocket engines. Except that we're increasing the energy of the electrons — not their velocity."

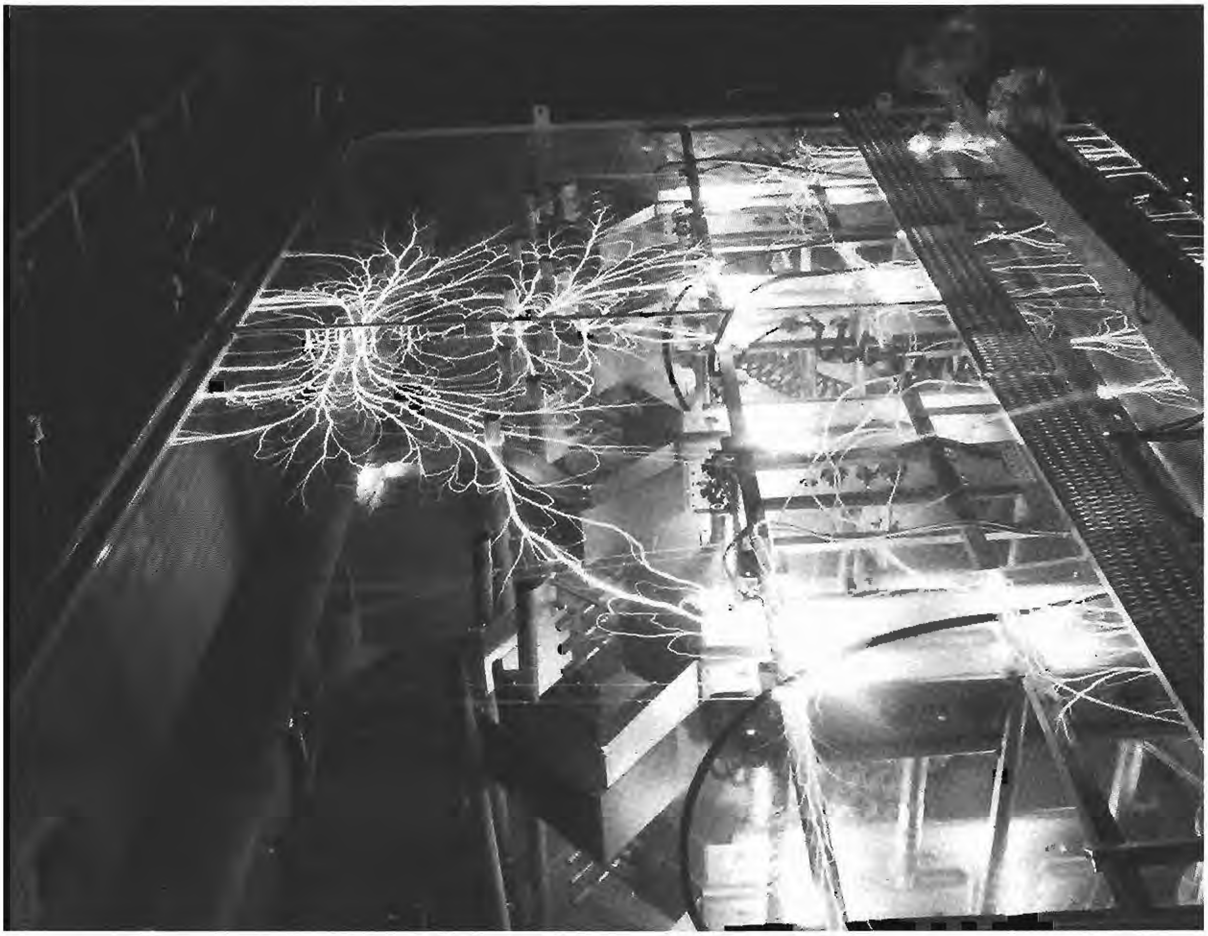
Matching Soviet advances, Sandia and Phillips built RADLAC to demonstrate the concept's feasibility, then scaled up the design. When completed in 1984, RADLAC II became the most powerful induction linear accelerator in the United States. During early testing, it fired an electron beam about twelve yards. The technical challenge involved keeping the beam stable and focused. "If a significant fraction of the energy in a single such pulse can be delivered to any military target, the beam would cause catastrophic destruction of that target," Prestwich and Bruce Miller predicted. By 1986, the Air Force announced that for the first time RADLAC II had fired an intense electron beam through the air, and that experimentation would continue to more tightly focus the beam.

Another Sandia approach to directed energy, the fission-activated laser concept, complemented the Excalibur x-ray laser experiments at Lawrence Livermore. Actually, Phil Tollefsrud and Dave MacArthur at Sandia had created the first nuclear-pumped laser in 1974. When probing the issue of whether nuclear reactors and lasers might be profitably combined for electric-energy production, they generated a laser beam by exciting carbon-monoxide gas with atoms from one of Sandia's pulsed nuclear reactors. Based on this success, Sandia established a program managed by Paul Pickard and Jim Rice to continue this research for SDIO. Using existing pulsed nuclear reactors at Sandia and the Idaho National Engineering Laboratory, testing began and fluid dynamics codes soon indicated that adequate beam quality could be achieved with near-term optical technology. Pulsed nuclear reactors brought two pieces of uranium together to produce a critical mass and release a burst of energy. Much smaller than commercial power reactors, these were sufficiently lightweight to be launched aboard spacecraft. The Sandia team envisioned eventual use of this technology not only for defense, but perhaps to propel spacecraft on interplanetary missions.

Sandia's analysis of possible counter-measures against an SDI deployment considered the use of decoys to draw fire from SDI-type weapons and exhaust their power, thereby easing the passage of real warheads. How could differences between the two be distinguished? Don Rigali, moreover, asked how the differences might be detected if the decoys and warheads were disguised inside insulated balloons. Seeking answers to these critical questions led to the formation of Sandia's DELPHI project. Suggested by Ron Lipinski, DELPHI came from the story of the Greek oracle who saw through Oedipus's disguise and recognized him as his mother's husband.

Once the name DELPHI had been chosen, Miller found words to fit the acronym: Discriminating Electrons with Laser Photon Ionization. Miller, Lipinski, Milt Clauser, Tom Lockner, and other Sandians developed the interactive discriminator concept to detect decoys. While passive sensors might not detect the differences between warheads and decoys, if beams of electrons were fired at objects in space, their interaction with the materials of the object would, through bremsstrahlung reaction, produce x-rays that would allow warheads to be distinguished from decoys. Bremsstrahlung, or "braking radiation," describes the process in which radiation is emitted as an electron slows down.

Larry Stevenson and Art Sharpe make adjustments in 1981 on the experimental RADLAC (Radiation Linear Accelerator) for directed energy research.

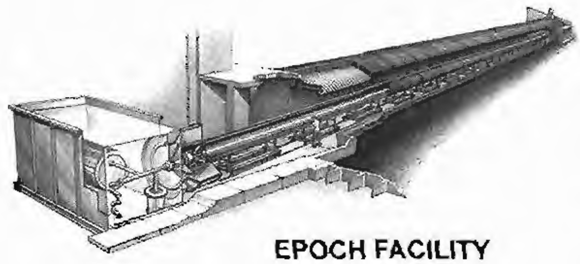


Electric arcs on the surface of the water in which RADLAC II was immersed create lightning-like effects. The electric discharge had no technical significance.

As DELPHI proceeded, it soon appeared that the high-energy electron pulses fired to detect warheads could also be used at higher power levels to destroy them. Rather than positioning DELPHI in space, it might remain on the ground and be launched into the upper atmosphere as needed. To test this concept, Sandia built the electron propagation on channels (EPOCH) facility.

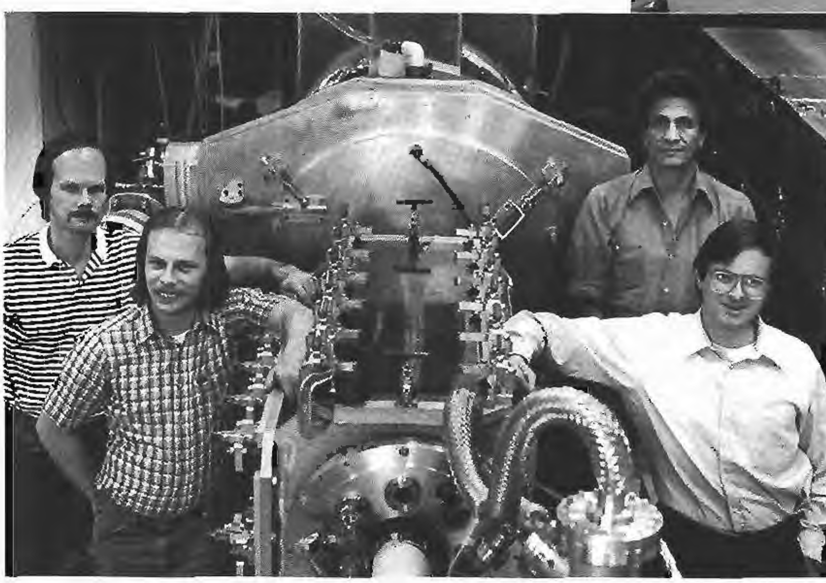
Sandia learned that electron beams did not travel long distances in a straight line. As the high current electron beams generated enormous electromagnetic fields they became unstable, whipping about like a fire hose under pressure. To keep the beams stable, Sandians conceived of using a laser beam to ionize a clear channel ahead of the electron beam, and to test this, Sandia built its EPOCH facility with a 184-foot-long propagation tube. It fired a krypton-fluoride laser and its companion electron beam down the tube. James Rice reported the beam followed the guidepath opened by the laser about fourteen feet into the tube at the first test. Three research initiatives followed: experiments to extend the beam travel farther along the tube, to develop lasers capable of blazing guidepaths through the upper atmosphere, and to reduce equipment weight, thereby permitting the launch of DELPHI systems into space.

Within a year, Sandia's propagation experiments had extended beam travel distance to the end of the 184-foot EPOCH tube, the longest electron-beam propagation achieved to that time. This opened possibilities for its use in flash x-ray radiography, welding, and materials properties research in addition to potential strategic defense applications. "It's a unique facility," said Lipinski, "able to address the issues associated with long-pulse, long-distance



Schematic diagram of Sandia's EPOCH facility used for directed energy experiments with electron beams.

Above: Ron Lipinski gives a briefing on the EPOCH facility to SDIO director General James Abrahamson. Behind them is the 184-foot propagation tube.



Left: In 1985 this Sandia team used this electron accelerator (known as MIMI) to demonstrate that an ultraviolet laser could create an ionized channel to guide an electron beam. *Left to right:* Gordon Leifeste, Charles Crist, John Leija, Charles Frost.

e-beam propagation." SDIO reported that DELPHI produced a discrimination signal that gave "a very high confidence sorting of decoys from RVs and probably destroys all electronics on board any such vehicle identified." With these discrimination and electronics "kill" abilities, SDIO expected DELPHI to enhance opportunities for rocket-launched, kinetic weapons to destroy incoming missile warheads.

By the mid-1980s, the principal SDI focus switched from directed-energy (beam) weapons toward kinetic energy (impact) weapons that might be deployed in the first defense phase while research on beam weapons continued. George Dacey in 1984 penned a perceptive explanation of the rationale supporting kinetic weapons: "As accuracy increases, the power needed for destruction decreases. With sufficient accuracy, the explosive power required to destroy a target is below the nuclear range and into the conventional range. In fact, one can imagine destroying a target without any explosive at all — if you have sufficiently high kinetic energy, that is, a high-velocity device that hits the target directly in its most vulnerable spot. The whole thrust of guidance, of acquisition, of pointing, of intelligence — in the sense of target seeking and target discrimination — leads you to the possibility of destroying enemy targets without the use of nuclear weapons."

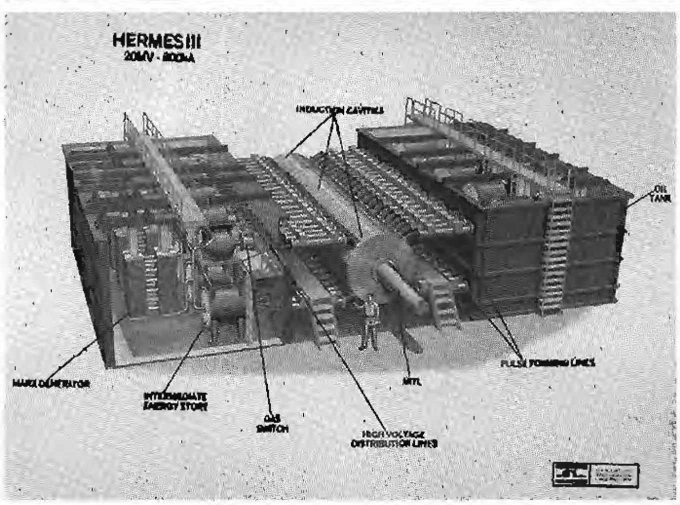
Sandia, compared to other laboratories, took a cautious approach to SDI,

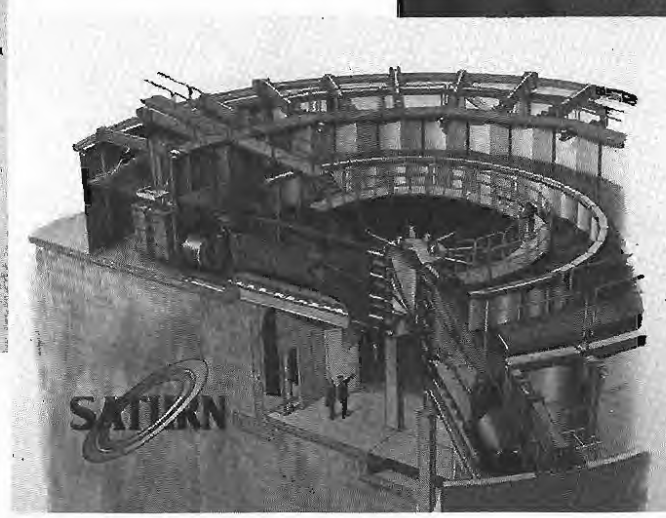
Right: The crowd assembled for the 1980 dedication of Sandia's Particle Beam Fusion Accelerator (PBFA) watches technicians at work in the water around the machine.

Top left: Jesse Harness checks one row of the bank of 128 Marx capacitors in the Hermes II radiation simulation facility. Hermes II tested the effects of gamma rays on weapons for twenty years at Sandia before its retirement.

Bottom left: Schematic diagram of Hermes III, built at Sandia during the 1980s for weapons effects testing. It was the world's most powerful source of gamma rays.

Bottom right: In the late 1980s Sandia converted its first Particle Beam Fusion Accelerator into Saturn, a powerful x-ray accelerator. This schematic diagram indicates Saturn's size — note the people shown beneath the central diode.





emphasizing technology development as opposed to full-scale demonstrations. Dacey also enjoyed Sandia's role as the Red Team — the "honest broker" — for SDI, and urged that Sandia take on new work only when it had something technically unique to contribute. As a result, the SDI program never amounted to more than ten percent of Sandia's budget. When added to Sandia's research on conventional weapons for the Defense department, however, it helped make reimbursable work-for-others another leg in Sandia's programmatic triad.

PULSED POWER

Although directed energy development for SDI garnered the most media attention during the early 1980s, Sandia advanced its pulsed-power sciences primarily for weapon effects testing and ICF. It built three new and powerful machines for these purposes: Hermes III, Saturn, and PBFA II.

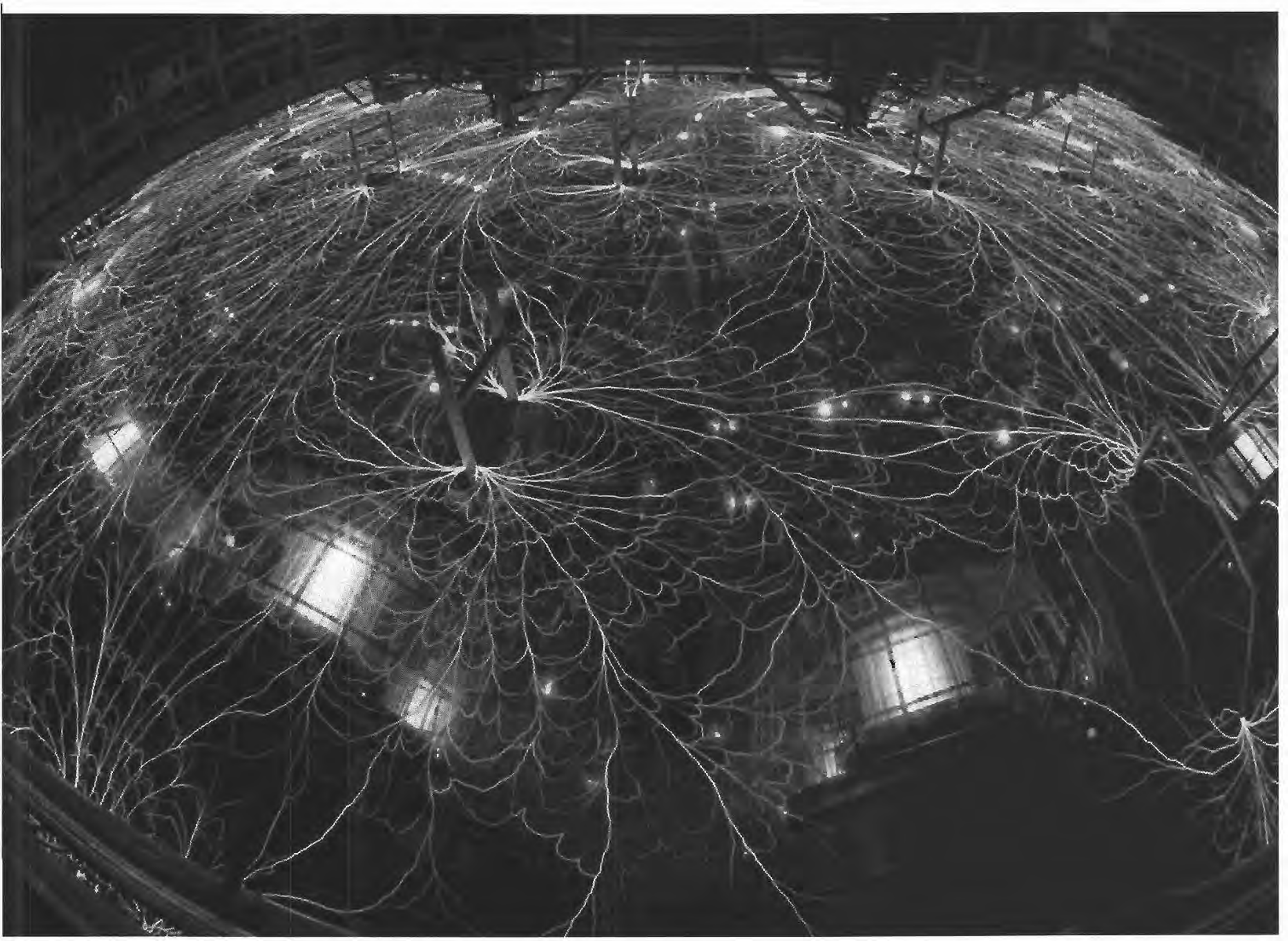
Sandia's third high-energy-radiation, megavolt-electron source, Hermes III, was designed to evaluate the vulnerability of

Sandians and contractors perform maintenance on Hermes III between tests in 1988.

weapon components to radiation effects. A very large machine that generated a bolt of electrons, causing a flood of bremsstrahlung x-rays when it struck a metal target, Hermes III, managed by Juan Ramirez, became a powerful tool for weapon testing. Based upon new acceleration technology developed by Sandia and Pulse Sciences, Inc., with program support from the Defense Nuclear Agency, it represented a factor of ten increase in capability compared to that of Hermes II built in the 1960s and operated for twenty years.

Hermes III was large enough to test tanks, missiles, satellites and other military equipment in intense gamma-ray beams. If the systems failed the test, their designers went back to their computers to develop radiation-hardened shields or electronics to ensure survivability. "About 20 to 30 percent of our hardware has failed at Nevada because we haven't done the above-ground laboratory tests well enough," said Jim Powell, manager of Sandia's simulation technology, adding a note on the cost effectiveness of Hermes III, "Nevada uses a real nuclear weapon and it's very expensive. Hermes will allow us to be more extensive and correct the deficiencies before you go to Nevada. You design it. Test it here. Redesign it and retest it. Then you can go to Nevada for the real thing with some confidence you are going to pass the test."

On the other hand, Saturn, Sandia's companion accelerator, was not entirely new. When research on the first particle beam fusion accelerator (PBFA) concluded and the construction of PBFA II began, Sandia converted the first PBFA, managed by Doug Bloomquist, into the most powerful source of x-rays on earth. Renamed for the planet



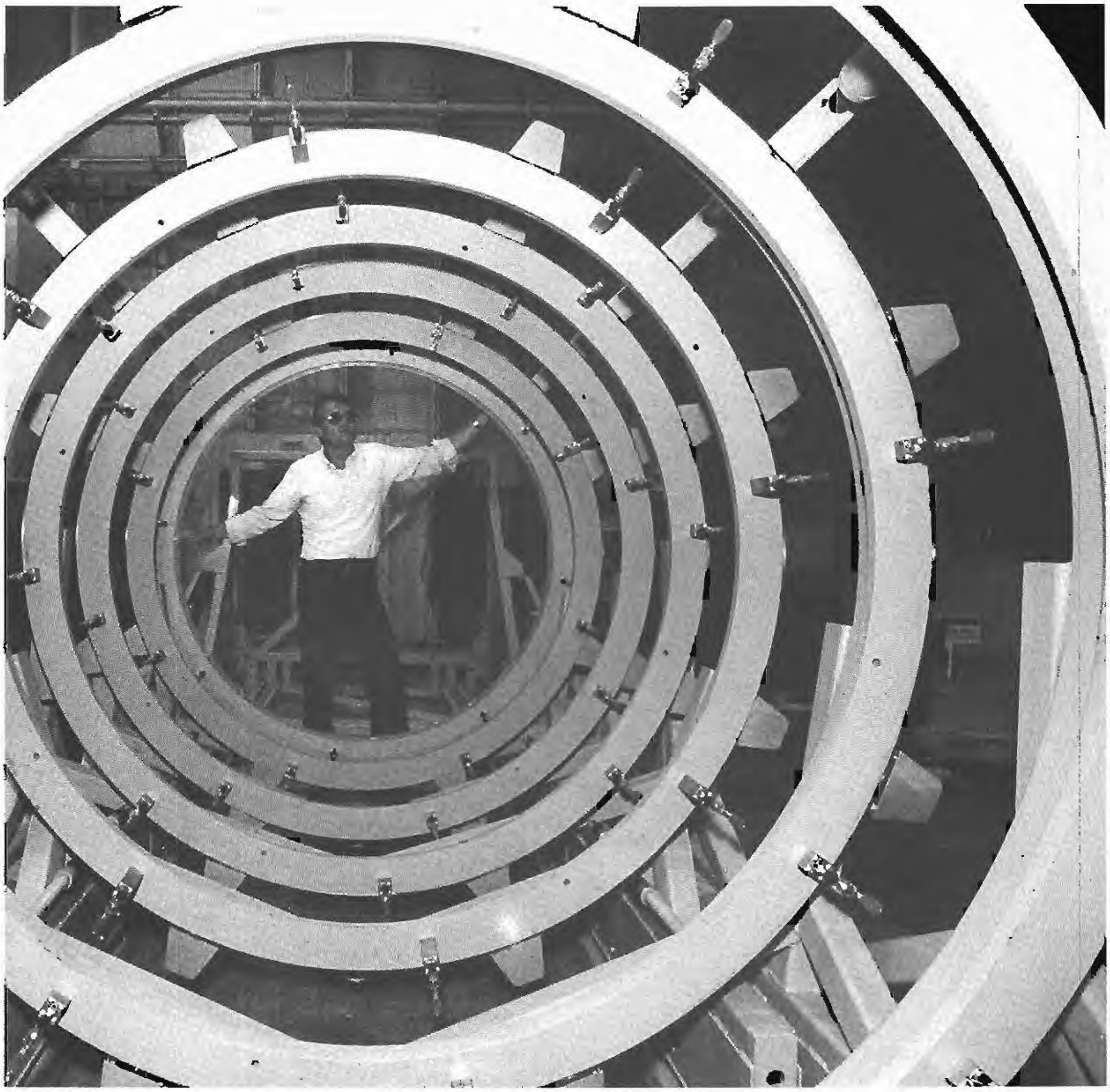
Electrical arcs created this pattern at Sandia's Particle Beam Fusion Accelerator II. PBFA II provided an experimental test bed for using ions to achieve inertial confinement fusion for national energy security.

Saturn, because it had concentric rings in its central diode, the refurbishing included upgrades in the energy storage and pulse-formation sections and replacement of its magnetically insulated transmission lines with water transmission lines carrying power to the central ion diode.

Twice as powerful as Proto II, Saturn not only tested weapon vulnerability to x-rays, it also enhanced research into x-ray laser physics. The first testing done in Saturn checked the x-ray hardening of Sandia's arming, fuzing, and firing system for the Trident II warhead. Jim Powell explained that Saturn could support the SDI program by assessing the equipment vulnerability against countermeasures in space. "One way to poke a hole through defense in space," Powell asserted, "is to set off nuclear explosions with x-ray pulses in space."

Saturn fired successfully for the first time in January 1986, joining Hermes III in Sandia's above-ground testing repertoire. However, neither of these, nor other particle accelerators, obviated the final requirements served by underground nuclear testing. "Machines never completely duplicate," Jim Powell stressed, "all of the individual radiation effects of an underground test."

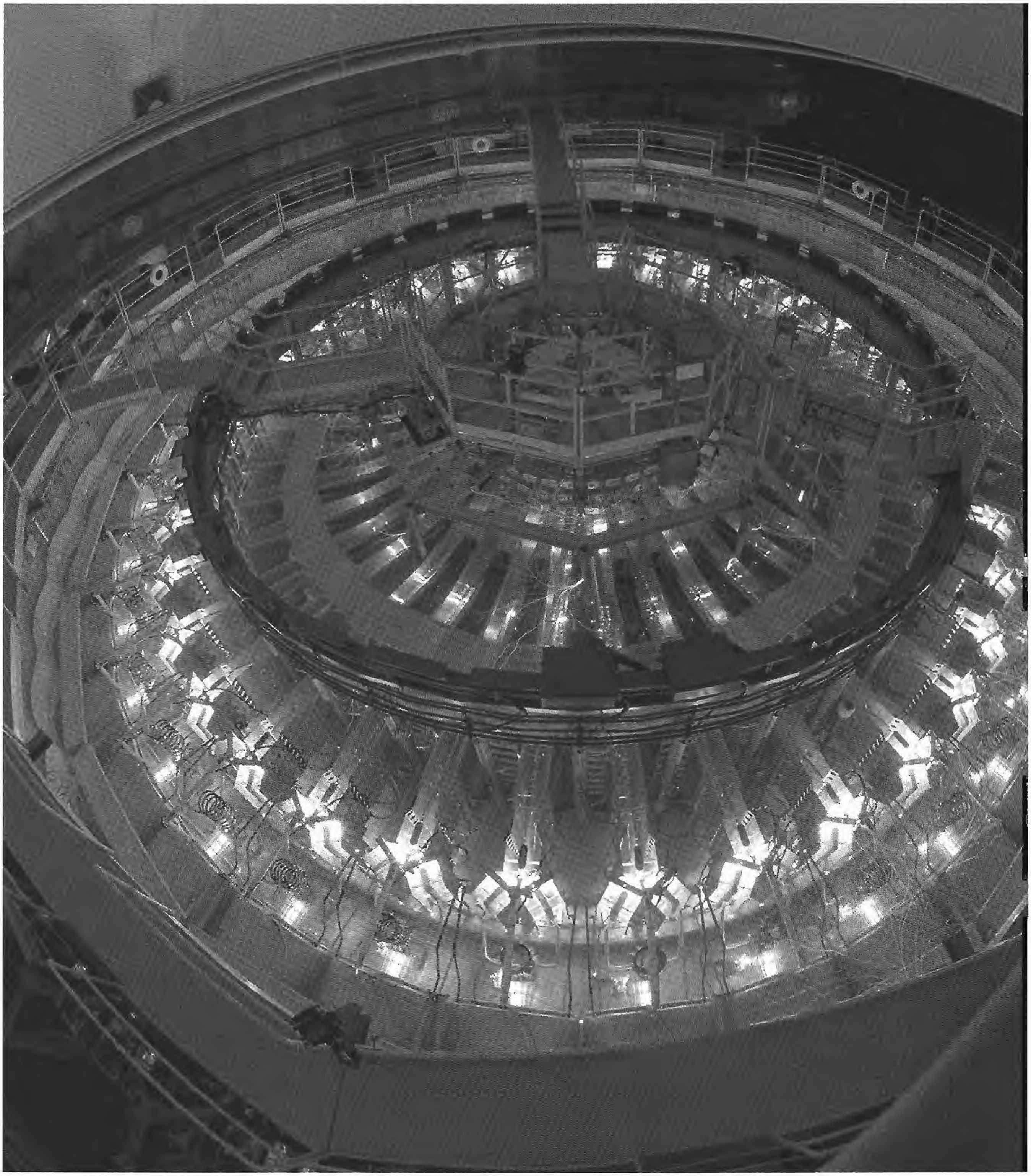
In 1985, Pace VanDevender explains the ion diodes of PBFA II to Adam Klein, counsel for the House Armed Services Committee.



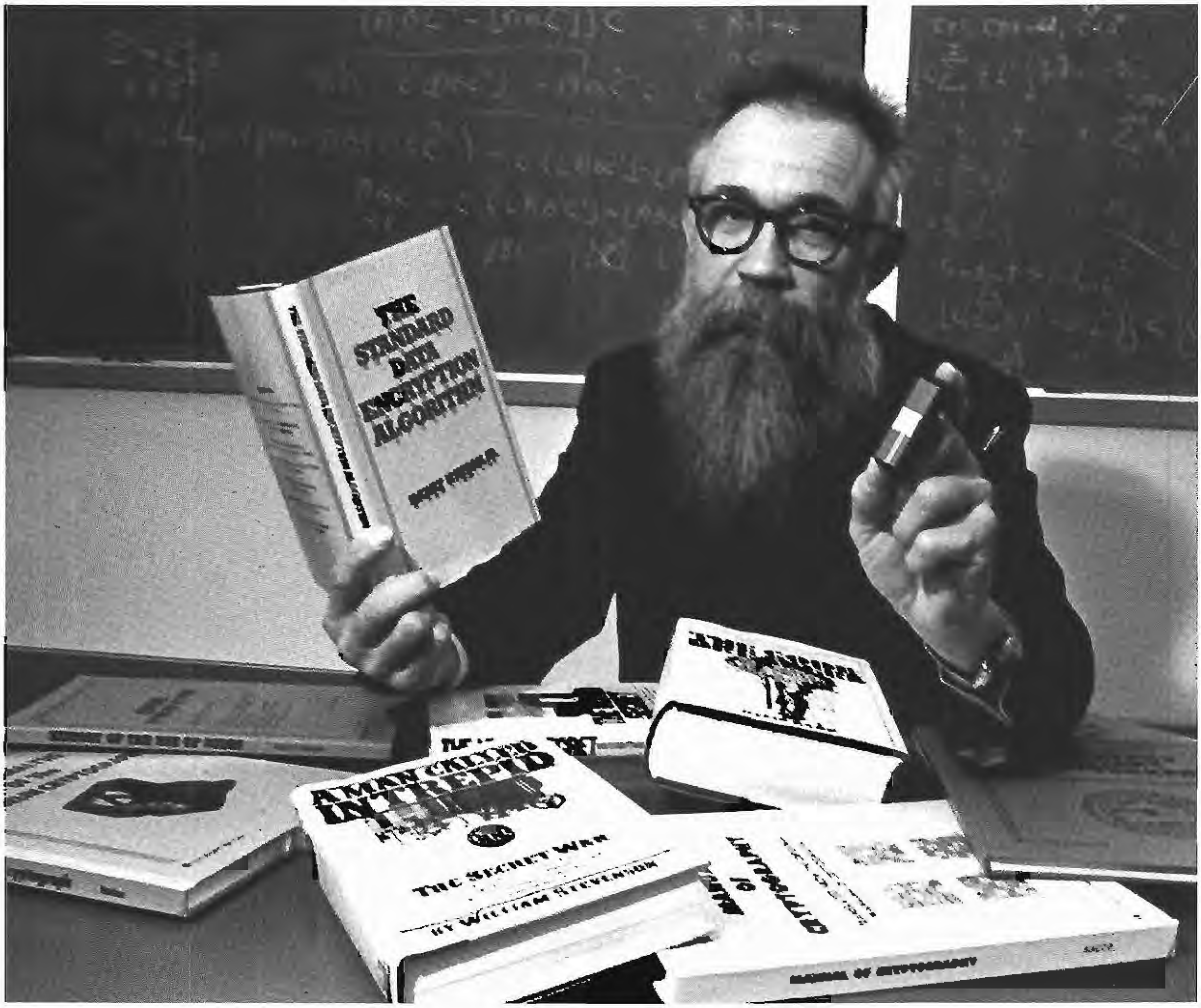
Ken Hanks, manager for the Saturn Accelerator project in 1987, displays the handling fixture for Saturn's transmission lines.

By late 1985, under Pace VanDevender's leadership, PBFA II neared completion and Sandia had become DOE's lead laboratory for studies of light ions for achieving ICF. Consisting of thirty-six power modules circling a central experimental hub, PBFA II delivered focused pulsed power in the form of lithium ions to the hub from all directions. Ahead lay research toward the development of a focused lithium ion beam to deliver up to 100 trillion watts of power per square centimeter onto deuterium-tritium fuel pellets no larger than a BB.

Don Cook, manager of fusion research, pointed out that focusing the ion beam would be challenging. "Particle beam accelerators are extraordinarily powerful and efficient," he said, "but you must be able to focus their output on the fuel pellet." Unfortunately, focusing turned out to be much more difficult than anyone had envisioned. Experimentation at PBFA II with the mechanics of energy output, with focusing, with different sources of lithium ions, and with the conversion of ion beam energy into x-ray energy, continued throughout the 1980s and into the 1990s.



In 1996, Saturn produced a record-breaking 85 terawatts of power — more than 50 times the output of the entire U.S. utility grid.



Gus Simmons, holding a code encryption device in his hand, received the DOE E. O. Lawrence Award in 1986 for his role in developing codes for the command and control of weapons and for treaty verification.

The imploding plasma research begun for x-ray laser pumping continued and in 1996 set new records for creating powerful x-ray sources for ICF and weapon physics. Yonas, back from his SDIO assignment and a subsequent stint in private industry, took over management of the ICF program, which was converting PBFA II to an imploding plasma driver in the hope of creating a 100-terawatt pulse. This was twenty-three years after he had envisioned the 100-terawatt level as that needed for fusion ignition.

Sandia during the 1980s thus developed three of the most powerful particle accelerators in existence: Hermes III for gamma-rays, Saturn for x-rays, and PBFA II for ion beams. By the mid-1990s, Roger Hagengruber of the exploratory weapon group declared that the near-term goal was to advance the x-ray environment demonstrated on Saturn to even greater energy in PBFA II. With experimental data obtained from PBFA II, Sandia expected to extrapolate x-ray sources for weapon-related studies to higher levels, then to build an even larger accelerator for service during an underground testing moratorium.

AUTOMATED SECURITY

When asked in 1986 for his views on future weapons design, Glen Otey said, "I think we have gone as far as reasonably makes sense in pressing weight and volume." He predicted the main features of future designs would include small, rugged, reliable, and smart weapons. Charlie Winter echoed these observations, pointing out that Sandia was working toward a weapon that completely sensed its surroundings. "It might carry with it a map of where it is allowed to go off," Winter foresaw. "It might carry with it a description of the people who are allowed to operate it. It would keep track of what physical environment — temperature, pressure, humidity — it has been exposed to, and figure out whether it exceeded its environmental limits."

Such smart weapons offered increased safety, security, and use-control, the Sandia specialties known collectively as surety. When DOE selected Sandia as its center of nuclear safety excellence, Jim Ney, manager of the safety group declared, "Our goal is to make the unthinkable truly impossible." Pointing out that safety features were never add-ons but fully integrated aspects of the designs, Ney asserted that Sandia's "weapon designers go to work on them the day a weapon system hits the drawing board."

To improve use-control for smart weapons, Sandia mathematician Gus Simmons led an effort at Sandia during the early 1980s to develop automated code-handling systems for permissive action links (PAL). The goal was a design allowing the assignment of secret command and control codes by remote means, rather than by on-site recoding by military teams at each storage site. Automated codes would provide increased security and also maintain more accurate records of weapon readiness. Sandia completed its automated PAL code handling system by 1987, providing the U.S. European Command with automatic means of replacing nuclear weapon security combinations, and it began the design of another system for the U.S. Strategic Air Command.

History revealed that breaking the communication codes used by the Axis powers during World War II contributed immeasurably to Allied success. For control of weapons, Sandia during the 1980s sought codes that could not be broken, or at least would take so long to break that wars would end before it was done. "It must withstand mathematical analysis," Simmons explained, "because control is only as good as the information is secure."

Mathematicians Jim Davis and Diane Holdridge at Sandia's Cray computer used during the 1980s to factor large numbers.

In 1982 the banking industry used codes for electronic-fund transfers with strings of numbers so long that they seemed uncrackable. Breaking such a code required

Dorsey Bishop opens the panel on an inert B61 to show the PAL controller connector and various other switches.

factoring the numbers. Essentially an empirical process, factoring long numbers required much time and effort, but Simmons learned from a Cray engineer that this computer could sample clusters of numbers simultaneously, affording chances at faster solutions to factoring problems. A veteran of anticipating and finding vulnerabilities in weapon designs — known as "black-hatting" — Simmons set out to factor very large numbers, joining with colleagues Jim Davis and Diane Holdridge. Using the vector-processing ability of a Cray, they soon factored numbers that were 58, 63, and 67 digits long, and in 1984 they factored the 69-digit Mersenne number. This number, considered unfactorable since it was identified by French mathematician Marin Mersenne in the seventeenth century, took only thirty-two hours to factor on Sandia's Cray. Simmons' team broke the number down into three factors. "You can't help feeling triumphant," said Simmons, "after solving a problem that has been around more than three centuries."

That same year, the inventor of another encryption system called the "knapsack" offered a $1,000 prize to anyone who could break its code. Many tried, but Ernest Brickell and colleagues of Sandia earned the prize with a fast and elegant solution, making 1984 a banner year for black-hat mathematics at Sandia. Simmons became convinced that the key to solving large-scale computational problems depended as much on the design of the computer as its speed. "The exploitation of machine architecture," he said, "is a whole new way of doing mathematics."

Human Resources

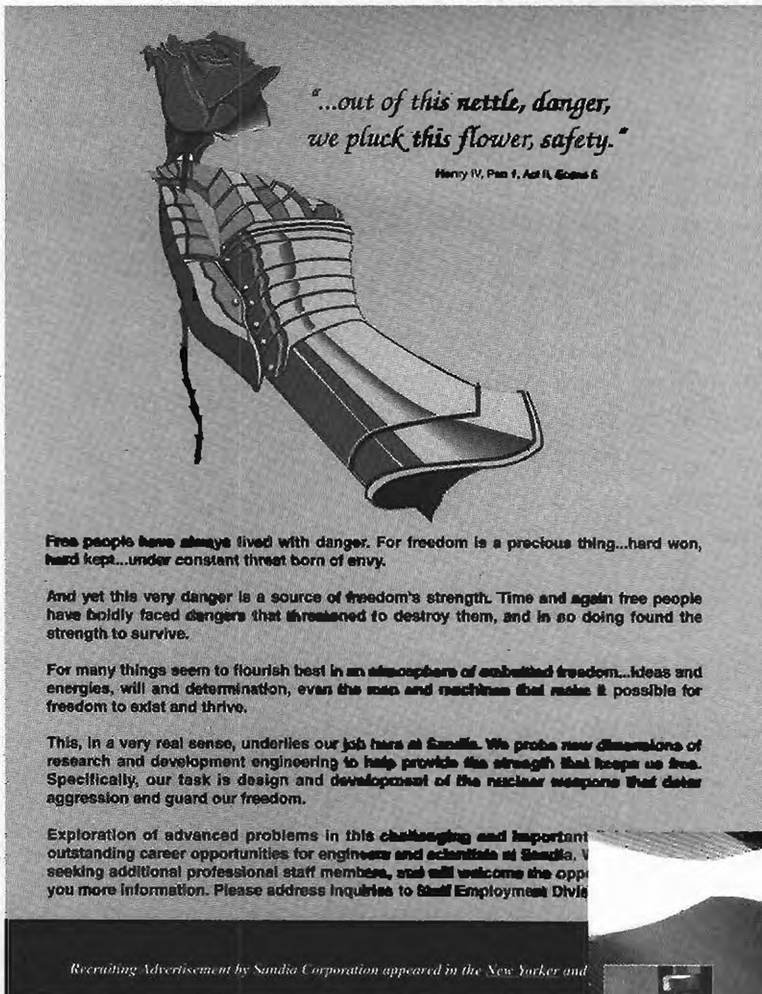
Sandia's Human Resources Division deals with the people side of Sandia. Good personnel practices have been fundamental in establishing Sandia's outstanding work force and integral to Sandia's success. Human Resources representatives are usually the first official contact a new employee has with Sandia and the last upon his or her termination or retirement. The Human Resources organization has been responsible for employment, employee records, education and training, labor relations, benefits, wage and salary administration, diversity, and equal employment opportunity. Whitley C. Scrivner, Personnel Director in 1962, said, "Once employee requirements for the year are outlined, we try to fill them with the best candidates available." From the beginning, Sandia's hiring standards were high, echoing those at Bell Laboratories: only the top 10 percent of graduating classes from university engineering schools were hired.

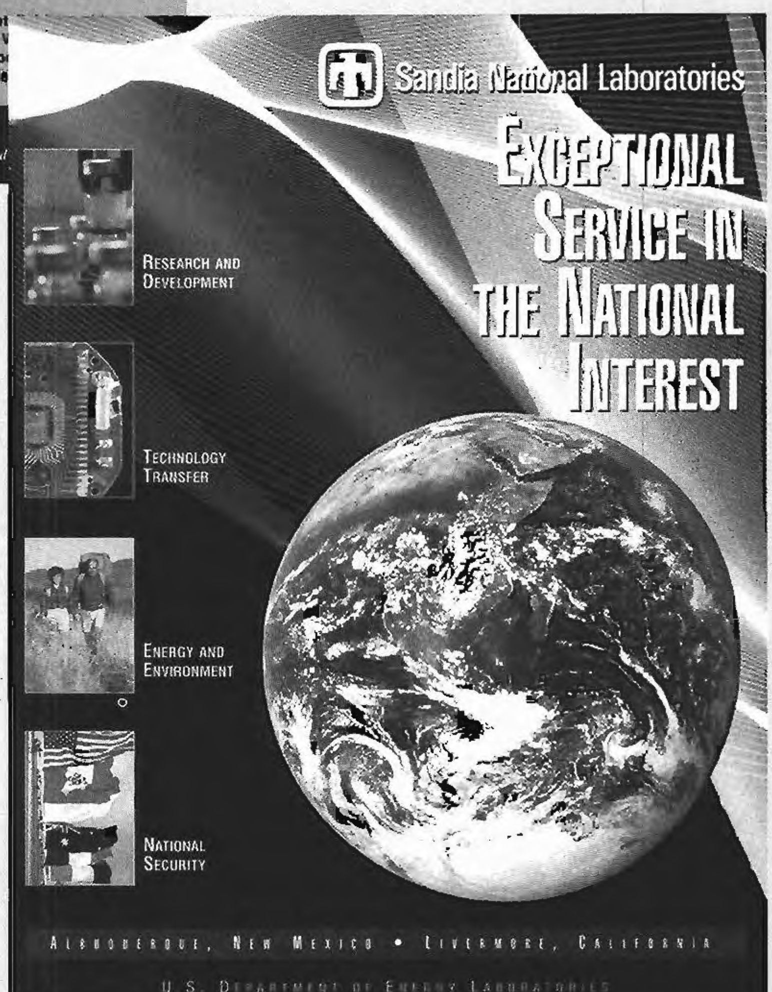
In 1962, Sandia's employee population totaled 7,940, including 136 Ph.D.s, 598 Master's degrees, and 1,805 Bachelor's degrees. By 1996, there were 8,450 employees, including 1,445 Ph.D.s, 2,215 Master's degrees, and 1,001 Bachelor's degrees. The Ph.D. hiring momentum began in the early sixties as a result of the strategic decision to pursue science-based engineering.

In the 1960s recruiters spread out across the country visiting selected colleges and universities and at least 20 technical institutes to deliver their message of exciting career opportunities at Sandia, ensuring an infusion of personnel in the latest technical and management sciences. Sandia sent out technical staff members as recruiters, instead of professional recruiters. For BS and MS candidates, Sandia recruiters usually accompanied teams from Western Electric, AT&T, Southwest Bell, and Bell Labs — of these, only Bell Labs also used technical people to recruit. Sandia conducted its own campus Ph.D. recruiting program. So few women completed technical degrees then that a 1962 *Lab News* article thought it worth noting that three women were hired as engineering technicians as part of the influx of qualified employees trained in the fields of electrical, mechanical and chemical engineering, drafting, photography, chemistry, and health physics.

By 1962, a computer database recorded personnel actions and tracked the diverse skills of employees. Personnel representatives helped organizations locate qualified people for placement as openings occurred and encouraged employees to broaden their skills and abilities to fill better jobs. Staff applied for internal job openings via a posting and bidding process.

Sandia assumed a commitment to equal employment opportunity (EEO) with the first contractual agreement with the Atomic Energy Commission and Western Electric in 1949. After John Kennedy's Executive Order in 1961 establishing a Presidential Committee on EEO, Sandia incorporated an Affirmative Action plan in hiring practices. As minority hiring was implemented, Sandia worked to improve skills of disadvantaged employees to improve hiring in professional areas. A Women's Program Council was appointed in 1972 to emphasize recruitment and promotion of women; in the mid-1970s, additional affirmative action programs were initiated to address age, Vietnam veterans, disabled veterans, and handicapped persons. In 1979, several targeted outreach committees were initiated to support employees and assist in minority recruiting. By 1992, Sandia had created a Diversity Leadership and Education Outreach Directorate that included all Equal Employment and Affirmative Action programs.





Recruiting posters for personnel: above, 1956 and right, 1995.

A strategic staffing initiative began in the early 1990s to effectively manage skills mix needs through strategic hiring, internal realignment, and retraining. Sandia Personnel Department's adherence to these recognized policies has supported fair and equitable hiring practices and promoted excellence in Sandia's work force.

George Dacey was president of Sandia from 1981 to 1986.

DACEY OPTIMISM

Although President Reagan's policies forced retrenchment in energy programs, Sandia during the 1980s enjoyed a vital role in a growing defense program. Accepting roles in the President's strategic defense initiative and in advanced conventional munitions research, Sandia prospered under Dacey's leadership. During these years, Sandia's staff grew from 7,800 to a new peak of 8,400, although this mattered little to Dacey, who once remarked that he would rather manage a small but first-rate laboratory than a second-rate laboratory with 80,000 employees.

During the 1980s, Sandia began adding one or more major office and laboratory buildings yearly. This clearly marked a growing appreciation by DOE and Congress of Sandia's accomplishments and needs. Still, Sandia's facilities left much to be improved. A reporter for *Smithsonian* magazine, for example, wrote in 1985, "Sandia is a cluttered sprawl of polystyle buildings — countless buildings that obviously accreted hurriedly over time and without the slightest thought for exterior esthetics."

Steps toward ameliorating these conditions began under Dacey's administration. When Ward Hunnicutt and Joe Stiegler reviewed plant engineering and maintenance in 1984, recommending increased and streamlined staffing to keep apace of Sandia's growing facilities needs, Dacey approved and Arlyn Blackwell orchestrated campaigns at Livermore and Albuquerque for greater consideration of esthetics in site planning. As technical support vice president, Bob Peurifoy continued efforts to raze the dilapidated temporary buildings installed during the 1940s and to have technical managers become principal advocates for new technical facilities. Within a decade, the results of these and related efforts became evident in Sandia's significantly improved physical plant.

When George Dacey retired in early 1986, these achievements gave him ample reason for optimism. His optimism extended as well to new paths that technology was taking: "In particular, ... I see a number of strains coming together that I have felt for a long time were needed: one is emphasis on conventional deterrence and *defensive* nuclear weapons; another is emphasis on defensive instead of purely offensive strategies; and a third, yet to be adequately implemented in my view, is arms control negotiation *intermixed* with technical capability in such a way as to lead to stability."

Left: In 1969, Sandia's mailroom hired Irene Chavez, its first female delivery clerk. Chavez is shown here delivering mail to Sandia President John Hornbeck.

Below: Cathie Estill of Mail Services handles a small portion of the million pieces delivered every month in 1995.

Sandia's Mailroom

Mail is the lifeblood of any organization. Whether it arrives on paper or electronically, it is the information that allows everyone to do his or her job — indeed, it is the core of most jobs. In 1952, mail meant paper — tons of it. Eighteen messengers spent the day traveling around to 275 mail drops — visiting some of them as many as eight times a day. At the time, all 18 messengers were men, while the 20 clerks responsible for processing and maintaining accountability on classified correspondence were women.

By 1957, the Sandia mail system was handling a million pounds of paper a year. Nick Tarnawsky, section supervisor at that time, reported that in one month the mail section sent out 26,183 pieces of first class mail. The introduction of electronic mail and greater voice messaging capabilities has not reduced the amount of mail coming through Sandia's doors. A mail services team member pointed out in 1996 that Sandia received as much mail as the city of Las Cruces, New Mexico (pop. 67,000).

George Dacey, *right,* welcomes Irwin Welber to Sandia in 1986.

VIII

AT THE THRESHOLD

We bring something unique to our work ... We have people who have built these things, measured them, and understand them physically, and they understand the physics involved. So when we make an analysis, it's not based solely on paper, it's based on experience as well. That's unique. It truly is. We're not just a think tank.

Irwin Welber

Swift and at times surprising twists marked Ronald Reagan's second term. His administration's emphasis on national defense, the strategic defense initiative (SDI), and advanced conventional weapons meant continued growth in these programs at Sandia. Negotiations on arms control and test bans seemed at an impasse until the 1986 meeting of Reagan and Soviet leader Mikhail Gorbachev in Reykjavik, Iceland, one of the pivotal events leading toward an end to the forty-year Cold War. In the negotiations for the Intermediate-range Nuclear Forces treaty of 1987 and the Joint Verification Experiments of 1988, Sandia provided critical technical support, both to the negotiators in Geneva, Switzerland and in the technological research field. By 1989, the United States and the world had arrived at the threshold of a new era.

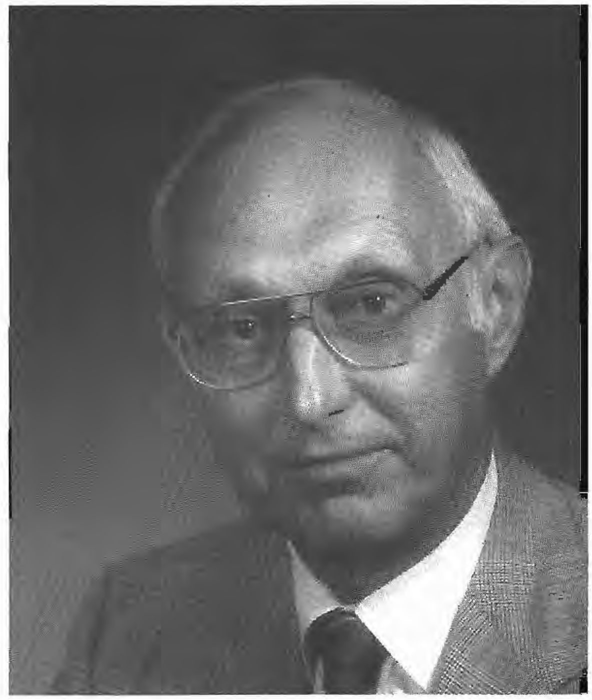
During the late 1980s, Sandia continued its traditional weaponization for the nuclear arsenal and conducted exploratory research for SDI and the development of improved conventional weapons. For applications in these programs and others, Sandia joined in urgent scientific races to develop high-temperature superconductors, photonics applications, materials improved by ion implantation, and conductive and piezoelectric polymers. For their winning research in these races Sandia's scientists earned the Department of Energy's highest commendations.

It is important to note that Sandia's emphasis on transferring its technology to the private sector began in 1986, preceding the Cold War thaw. Its technology transfer programs expanded in response to mandates from President Reagan and Congress that it seek to assist strategic industries supplying technology vital to national defense. Under the rubric of fostering economic competitiveness in global markets, Sandia sought to aid the national semiconductor, specialty metals, and other strategic industries in efforts to maintain the world leadership deemed imperative to defense objectives. Technology transfer therefore meshed well with Sandia's traditional programs.

WELBER'S CHALLENGES

When George Dacey retired in January 1986, his successor had been on the job several months, learning what was required of a Sandia president. Although he had served Bell Laboratories for thirty-five years, Irwin Welber knew little of Sandia before his arrival. He was aware that Sandia employed an expert technical staff, but if asked exactly what they did, all he could say was "weapon systems." This is why he reported to Sandia months in advance of Dacey's departure.

A New Yorker with electrical engineering degrees from Union College and Rensselaer Polytechnic, Irwin Welber had joined Bell Laboratories in 1950, specializing in microwave transmission systems and participating in the design of Telstar, the first commercial communications satellite. His defense experience consisted of working closely with the National Security Agency to enhance security for international microwave communications.



Irwin Welber, Sandia president from 1986 to 1989.

A positive and unassuming personality, Welber set out "to meet as many of the people at Sandia as I can and learn about their work." To achieve this, he made it his custom to have lunch at Sandia's cafeteria. Often taking a seat unannounced, he asked his table companions where they worked in the Sandia organization. After they answered, he introduced himself, "I'm Irwin Welber." One surprised Sandian replied, "Sure you are, and I'm the Pope!" Welber listened carefully and, to the delight of his companions, sometimes acted on the

President Ronald Reagan, *second from left*, and the National Security Council in 1988 hear Robert Barker, *standing at right*, present Sandia's Tactical Engagement Simulator System for combat training developed with Defense Nuclear Agency funding. The uniformed men in the background hold replicas of rifles with lasers for combat simulation that were designed by Mike Moulton's team at Sandia.

Irwin Welber and his executive vice presidents, Lee Bray and Orval Jones, in 1987.

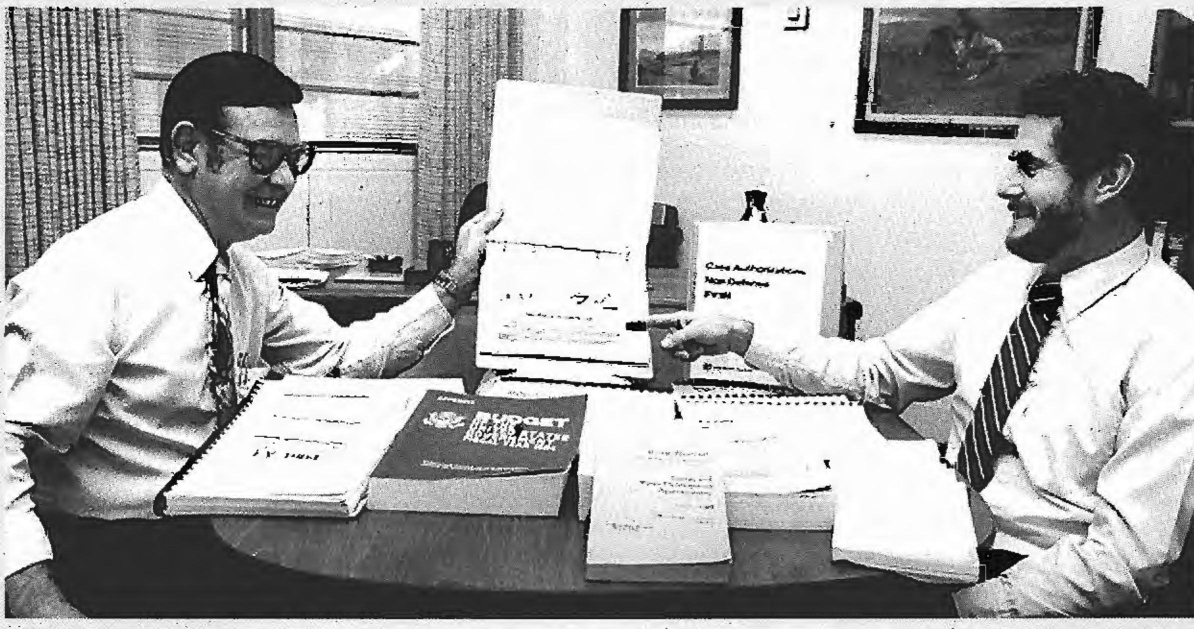
suggestions he received over lunch. Welber also paid regular visits to Sandia facilities outside of Albuquerque. Commenting that the Sandia flag flying in California was as important as the flag flying in New Mexico, he visited Livermore at least once a month. Sandians welcomed these personal contacts with top management.

With the transfer of Al Narath to Bell Laboratories and the retirement of Tom Cook, Welber had two new executive vice presidents, Lee Bray and Orval Jones. In the Welber reorganization of 1986, Dan Hartley became manager of Sandia's energy and environment programs, Everet Beckner of defense programs, and John Crawford took over management of Sandia California following Dick Claassen's retirement. Welber elevated exploratory systems to the top level and selected Roger Hagengruber to manage the verification, arms control, conventional weapons, and intelligence programs that grew in significance as the Cold War began to thaw.

Asked what were the greatest challenges confronting Sandia during the late 1980s, Welber responded that they included the growing but unstable program established for the Strategic Defense Initiative Office and the struggle to keep energy research active. "I feel strongly that a continuing and vigorous national research effort is needed," Welber said of energy research, "particularly in advanced coal technologies and geosciences, to moderate the effects of an energy crisis that will surely occur within a decade."

Answering the same question, Lee Bray noted that just fifteen years earlier Sandia had been single-purpose and largely internally driven, but as a multiprogram national laboratory with many new programs and sponsors, it increasingly encountered external drivers: arms control negotiations; environmental, safety, and health challenges; balance of trade and economic competitiveness issues; and especially federal budgetary deficits. Roger Hagengruber pointed out that by 1986 Sandia's

A FAR CRY FROM BOB CRATCHIT



Sandia Controller Paul Stanford and Paul Brewer of the budget and financial planning department reflect upon some of the documents they and their staff used in preparing the FY84 budget.

Financial Functions

Sandia's financial organization includes one of the Labs' most vital functions — the management of the budget allocated by the government. The organization includes financial reporting, manpower reporting, payroll, auditing, and budgeting. Both the disbursement of funds to programs and the salaries paid to employees are crucial to Sandia's daily operations.

Sandia's accounting functions were performed by the University of California until Western Electric took over the management contract in 1949. Western's original investment in Sandia consisted of Series F bonds purchased for $999.00 and a documentary stamp costing $1.00, which was purchased in connection with the issuance of 100 shares of capital stock. Since Sandia's accounting system was established by Western Electric personnel, it naturally resembled that used by Western. The AEC required only that it be kept informed of Sandia's accounts and procedures as long as they conformed to generally accepted accounting principles and yielded the data required by the AEC. Yearly budget reports were prepared to account for Sandia's expenditures and used for audit purposes.

The "case-cost" system was established in 1952. Borrowed from Bell Labs, this high-volume, job-order system of allocating resources to each lab function was easily adaptable to yearly cost-based AEC budgets. By the 1960s, research and development (R&D) had become predominant at Sandia and the case-cost system of authorization, monitoring, and budget control mechanisms was initially only used for R&D functions. Over time, however, it was expanded to cover all organizations and activities.

In 1967, following a directive by President Hornbeck to install a new budgeting and control system, Bill Stevens and Howard Stump recommended implementation of a "case system." This new concept, modeled after a management system at Bell Labs, assigned responsibility for cost control to the technical managers directly responsible for projects and was fully operational by 1969.

Property Accounting staff shown outside Building 880 prior to a Sandia Family Day in mid-80s. Front row from left: Cynthia Williams, Helen Moseley, Margaret Turner, Loraine Aragon, June Johnson. Second row: Felix Almaraz, Porfie Gonzales, Linda Canty, Darlene Welch, J. B. Hamlet, Robert Townsend. Back row: Mike McFadden, Cathy Gonzales, Bob Blount, Lulu Eady, Neita Tucker, Donna Coulter, Mike Apodaca.

Meanwhile, the computer revolution was also having a profound effect on accounting at Sandia. A 1966 report recommended that a totally integrated accounting and report system using the latest available integrated data processing and data communication techniques be implemented at Sandia. As a result, the IBM 7090 was replaced with the UNIVAC 1108/Executive II operating system, which was in place by the early 1970s. Later, on-line financial systems were in place that allowed greater access to budget information. These have been modernized through the years, eventually allowing the employees responsible for budget activities in their organizations to receive information at their desk top.

Although many individuals through the years have administered Sandia's complex accounting systems, it is fitting to mention a few by name. Charles Campbell retired as vice president of administration in 1976 after 26 years at Sandia. Campbell started with Z-division in 1947, and witnessed Sandia's expansion and the consequent changes in financial processes. In January 1985, Paul Stanford was designated as controller, and later he continued overseeing Sandia's money flow as financial advisor to executive management.

In 1986, T. R. Thomsen of Bell Laboratories, Dick Claassen, and Gene Ives inspect a weapon design at Sandia California.

reimbursable projects for new customers occupied twenty-seven percent of its employees and provided nearly thirty percent of its budget. Agility in anticipating and reacting to shifting national priorities, always a Sandia trademark, had become vital to Sandia's success.

Controller Paul Stanford noted that the growth years of the early 1980s had allowed Sandia to upgrade its facilities and to hire bright new people, but the burgeoning national budget deficit and the Gramm-Rudman-Hollings law imposing constraints on growth challenged Sandia's budgets during the late 1980s. Welber agreed that the "biggest challenge is the nation's budget deficit" — perhaps this was true for top management, but Sandia engineers during the mid-1980s were preoccupied with designs for complex nuclear weapons.

STRAINING AT THE THRESHOLD

"It's straining us," Orval Jones admitted, describing Sandia's heavily committed weapon design programs of the 1980s. In California, Sandia had major responsibilities for the W82 nuclear artillery shell, the W89 short-range attack missile (SRAM II), and advanced studies of a small intercontinental ballistic missile, while in New Mexico Sandia finished development of the Trident II W88 warhead, studied a warhead for the unique torpedo-tube-launched Sea Lance, and began designing the B90 depth/strike bomb. Although several of these projects were canceled during the 1990s, Sandians in 1986 saw few harbingers indicating they were at the threshold of a new era.

Participants signing the control documents in 1986 for the Trident II program. *Seated from left:* Dave Ponton (LANL), Bill Nickell (Sandia), Sam Jeffers (Sandia), Roger Teter (Lockheed); *standing,* Dan Hardin (Sandia) and Bob Carlson (Lockheed).

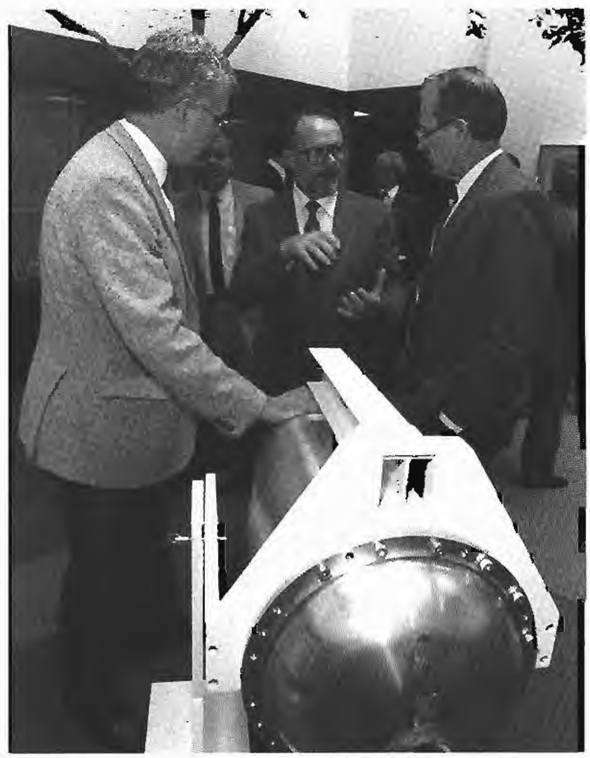
With final testing of warheads for Trident II and the Peacekeeper missiles underway in 1986, Sandia had begun several new assignments. After years of study by the Air Force, its contractors, and DOE preliminary design teams, Sandia enthusiastically undertook the engineering development phase in 1987 for the W89 warhead for SRAM II, as a replacement for the SRAM A and its W69 warhead that had been in the stockpile since 1972. The W69 warhead, lacking modern safety features, had been identified for years by Sandia as a primary candidate for stockpile replacement for safety reasons. SRAM II was a stand-off missile to be carried by B-1B and B-2 bombers and had longer range than the earlier system. Dave Havlik of Sandia California explained that the W89 design would enable bombers to carry more missiles in their launchers.

Bob Peurifoy displays the three arming, fuzing, and firing systems developed for the Navy's Poseidon, Trident I, and Trident II fleet ballistic missiles.

Jim Woodard, Carl Pretzel, Russ Miller, and Dave Havlik inspect a mockup of SRAM II, the short-range attack missile for which the W89 warhead was designed.

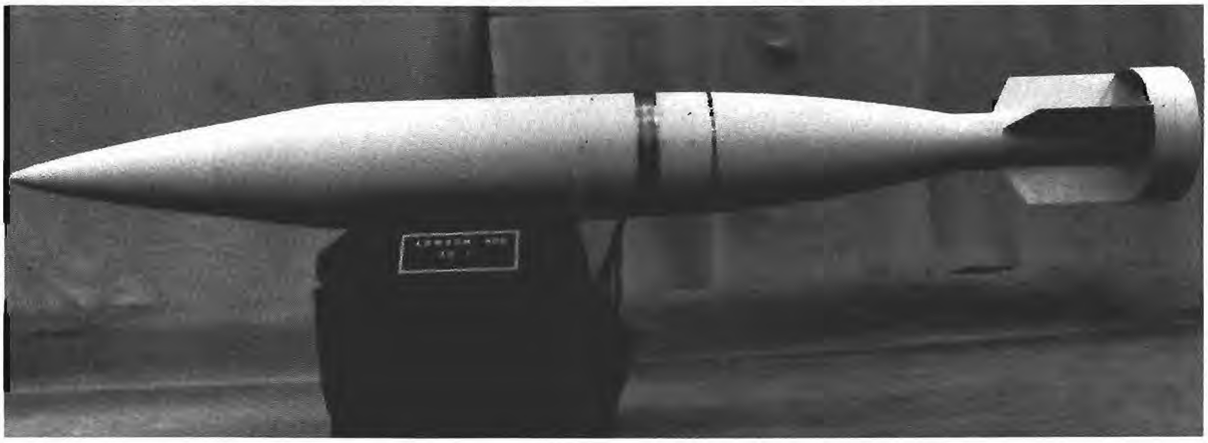
"The bomber crew's risks are reduced because they don't have to fly directly over an intended target," Havlik continued. "Instead, they will be able to program these missiles hundreds of miles away, release them, and then fly out of the danger zone."

Jim Wright's California team was responsible for the W89's systems engineering, including designs for the warhead structure and aircraft mating; the environmental sensing system; the gas-transfer system; and the safing, arming, and firing system. These presented several design challenges, notably developing components that could operate in temperatures ranging from below zero to near boiling with little insulation. As the first warhead to incorporate stringent new controls on nuclear safety, the W89 design provided such enhanced safety features as insensitive high explosive, a fire-resistant pit, improved detonation safety, permissive-action links, and command disablement. Production engineering (phase 4) began in 1990, but funding for SRAM II production ended in 1992. Fortunately, the SRAM-A missiles were retired anyway, beginning in 1992.

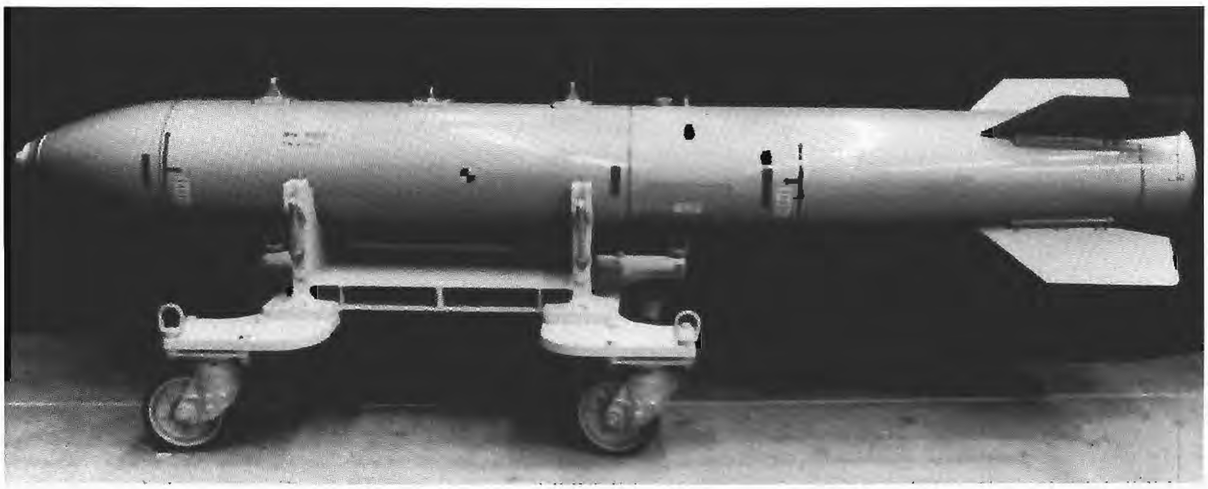


Dave McVey, *center*, describes Sandia's work on the Short-Range Attack Missile — Tactical (SRAM-T) in 1990 to Ron Oxburgh, *left*, of the United Kingdom, and Orval Jones.

Sandia had studies of the W91 for the proposed SRAM-T, a short-range attack or tactical missile, underway during the 1980s as well. This warhead and missile would have served the Air Force need for the ability to make air-to-surface attacks on targets in Warsaw Pact countries, and the same warhead also might have served on the proposed Army replacement for the Lance surface-to-surface missile. With a new and innovative firing set to increase safety, the W91 and SRAM-T passed severe flight tests.



Sandia's prototype of the Sea Lance anti-submarine depth bomb. This project was cancelled in 1986.



Sandia's prototype of the B90 nuclear depth strike bomb designed during the 1980s to replace the B57 for the Navy. The project ended due to funding limitations.

Orval Jones, however, perceived that this tactical weapon might be traded against nuclear artillery shells such as the W82. "The answer is political, not technical," he warned, expressing a similar opinion about the future of the small intercontinental ballistic missile.

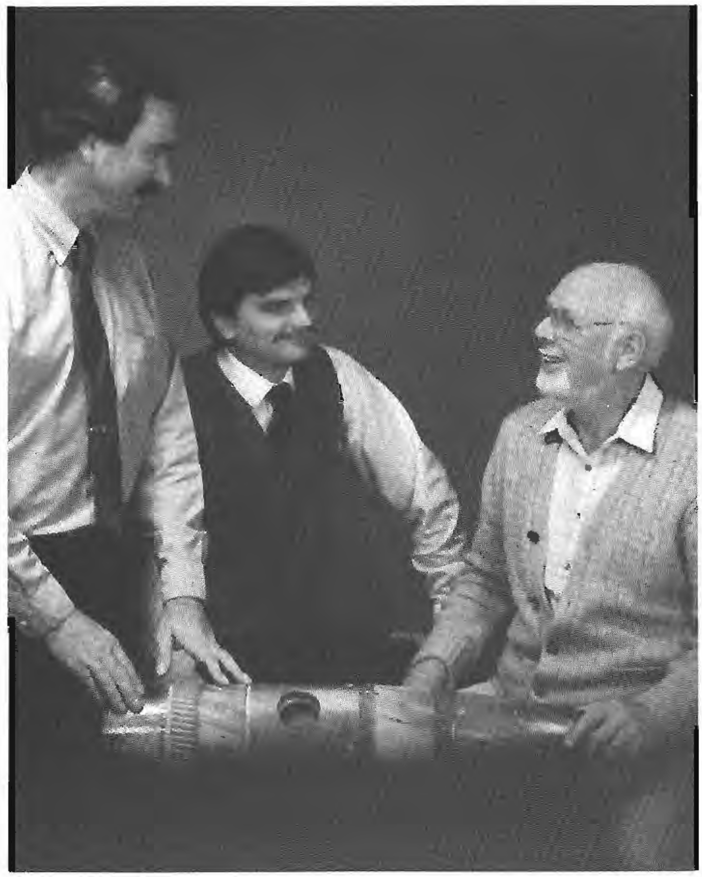
During the early 1980s Sandia had studied a warhead for Sea Lance. Designed for the Navy to replace the aging SUBROC warhead deployed in 1964, the Sea Lance was an anti-submarine stand-off weapon. Jerry Freedman, Stan Meyer, and Ray Reynolds managed Sandia's studies for this unique weapon. When launched from a submarine, its rocket ignited after reaching the surface to propel it toward its targets, where it reentered the water. Because the Sea Lance warhead occupied the weapon's nose, it posed interesting supersonic, subsonic, and hydrodynamic flow problems for Sandia's engineers. The phase 3 for this program was never authorized; but, using computer simulations and extensive field testing, Sandia had resolved most of the problems posed by Sea Lance concepts.

Sea Lance was cancelled in 1986, but in 1988 Sandia added another Navy design project. Advanced studies for a bomb to replace the B57, in the Navy inventory since 1963, culminated in 1988 with development authorization for the B90 nuclear depth strike bomb. The B90 had to be designed for two types of missions: as a depth bomb to be used against submarines and as a laydown bomb for strikes against land targets. For laydown, the B90's center-case parts had to withstand high-speed impact shocks and remain fully functional after the delivery aircraft had departed. Moreover, Sandia's design team adopted many of the arming, fuzing, and firing components of the larger B61 and had to fit them into a casing that was two feet shorter.

Sandia's B90 design achievements included a water-entry sensor to jettison the bomb's parachute when it hit the water. To accommodate a high-velocity delivery from low altitudes, Sandia's team developed a technique for the analysis of impacts on the bomb's nose. They used accelerometer data from actual impacts to design an energy-absorbing, crushable nose. This innovative design effort ended in 1992, however, when funding limitations led to project cancellation by the Navy.

After cancellation in 1981 of the W86, the earth-penetrating version of the Pershing II warhead, Sandia had continued its earth penetration studies with Wayne Young leading the project in Dick Braasch's systems development group. When the Strategic Air Command in 1985 requested studies of an earth-penetrating bomb to attack deeply buried, hardened targets, Sandia began investigating the possibility of using a modified B61 bomb with a high-strength steel casing for the purpose. By the end of the 1980s, these studies resulted in authorization for the phase 3 engineering development of this penetrator, the W91; however, the program was canceled in 1992.

Because portents of the coming conclusion of the Cold War were few, not many Sandians then had any inkling that the W91 warhead would become their last new nuclear weapon project. Glen Otey's prediction that future nuclear weapons would be rugged, reliable, and smart as bumblebees, however, applied with equal accuracy to the design goals of Sandia's growing conventional weapons program of the late 1980s.



Above: In the late 1980s, Sandia designed a video imaging projectile for battlefield reconnaissance. Holding a test unit are designers John Kraabel, Phil Zablocki, and Chuck Pignolet.

Below: Sandia in 1986 designed the Fire Ant, an experimental robotic vehicle that could spot and destroy moving armored vehicles and tanks .

Sandia's Airborne Remotely Operated Device (AROD) was developed for use of the Marine Corps in battlefield surveillance.

QUICK TURNAROUND

"Quick turnaround is a hallmark of Sandia," boasted Orval Jones, commenting on Sandia's reimbursable work on conventional and unconventional weapons for the military services during the late 1980s. Among the memorable achievements in this program were unconventional tank-destroying robotic vehicles, hovering reconnaissance vehicles, and advanced conventional bomb and missile fuzes.

Although prior to 1983 Sandia devoted little attention to robotic vehicles, by 1987 it had under design several remote-controlled vehicles, most for use where hazards were too great for humans. Among these was the remarkable low-cost anti-tank weapon named Fire Ant. Based on an all-terrain sports vehicle, Fire Ant was remotely controlled by an operator, who used a video system to see the target. The operator could maneuver Fire Ant into position and fire its on-board warhead to puncture armor at ranges of up to 500 meters. Irwin Welber described Fire Ant as typical of Sandia's "can do" approach. "In a period of about 90 days," he said, "our folks took three diverse technologies they have been considering for a year or two, combined them to make a weapon system, and successfully demonstrated it for the Army Science Board."

Welber was equally impressed by another remotely operated device he described as a "fancy little surveillance aircraft." At Marine Corps request, Sandia developed the Airborne Remote Operated Device (AROD) during 1986. Jim Jacobs, Duane Arlowe, and Neil Hartwigsen managed the design of this lightweight, hovering machine equipped with television cameras for battlefield reconnaissance. Using its microprocessor-controlled automation, fiber-optic communications, and high-performance airframe and control surfaces, a Marine platoon could use it to see what lay over the next hill or to search rooftops for hidden snipers. After thoroughly testing AROD, the Marine Corps asserted that it expected to put it into production for combat service.

"And there's more to come," Welber said, listing Sandia's conventional weapon concepts. "There's the concept of a shell, loaded with electronics, shot from a cannon.

John Souza in 1990 holds Sandia's Mk4 arming, fuzing, and firing system produced at Kansas City from 1977 to 1990, and used in the Navy's Trident I fleet ballistic missiles. One of the system's designers, Souza was the Sandian who stayed with the program throughout the production phase.

As it spins, the spinning enables the optical system to scan the terrain over which it's passing. It radios back that scan, so the field forces can see what is underneath the shell over a wide swath."

On the basis of its earlier success in designing electronics for Army conventional missiles, Sandia received assignments for electronic fuze designs for other missiles and for the application of its use-control technology to conventional Stinger missiles. The Army wanted to retrofit its Stinger missiles with devices that would prevent their use if they were captured or obtained by hostile forces; at the same time, the add-on retrofit should not make the weapon heavier or more difficult to use. When the Stinger production contractor turned to Sandia for assistance, Welber declared that Sandians, with their "can do" approach, had found solutions to this design problem and delivered prototype hardware within six weeks.

Late in 1984, the Army Deep Battle Laboratory was involved in developing a more flexible, deep battle doctrine concentrating on smart conventional weapons and sensors that could put an attacking force at risk deep into the second echelon. General William A. "Dutch" Shoffner met with laboratories and technology agencies in a search for new technology that could help the Army implement the new strategy. At Sandia, he was looking for an all-weather, day and night, airborne sensor system to detect and identify a variety of mobile weapon platforms on the battlefield. Max Newsom and his advanced project group responded with a proposal to use Synthetic Aperture Radar (SAR) as a sensor, if an Automatic Target Recognition (ATR) system could be designed to identify the SAR images. To make SAR/ATR useful on battlefields, Sandia's radar, computing, and image-processing specialists had to advance the state of the art. With Shoffner's approval, Sandia undertook this high-risk development program in 1986.

During the late 1980s, the U.S. semiconductor industry made great strides, producing the supercomputer and image-processing microchips that Sandia and the associate agencies applied to SAR/ATR. The Sandia guidance and control team led by Ron Andreas made revolutionary improvements in motion compensation systems to improve the SAR focus. Using this new technology, Michael Callahan and the radar development team came up with a miniature, all-digital SAR. Innovative image-processing algorithms developed by Larry Hostetler's team permitted the identification of potential targets. The uniqueness of target SAR signatures was demonstrated in numerous flight tests by the systems groups managed by Tom James and Carolyn Hart. These advances combined to permit the development of powerful and compact image-processing systems that could analyze SAR data while still airborne over target areas. Paul Eichel, Dennis Ghiglia, and Charles "Jack" Jakowatz, moreover, designed an award-winning software program capable of correcting the distortions caused by changing aircraft positions and signal interference to produce high-resolution target area images. Having demonstrated the requested system to Shoffner and the Army, Sandia subsequently pursued other uses for its advanced SAR/ATR system. For example, Sandia worked with the U.S. Coast Guard to apply the system to the detection and tracking of oil spills.

Barney Barnett and T. J. Williams in 1988 display the principal electronic modules and safety switches Sandia designed for the B83 bomb. Williams holds the components, which are encapsulated in the round casing held by Barnett to protect them against environmental damages.

Randy King peers through a fragmentation casing made by Mike Clough and Bruce Higgins for the advanced medium-range air-to-air missile (AMRAAM) upgrade.

In early 1989, the Navy and Air Force requested Sandia's assistance for design services on conventional bombs and missiles. For the Navy, Sandia contributed designs for a conventional bomb casing, its penetrating aerodynamics, its retardation system, and its arming, fuzing, and firing system, all of which were Sandia specialties. For the Air Force, Sandia undertook design work for a conventional missile fuze under a new arrangement — as subcontractor to a private defense contractor.

Ironclad rules required that Sandia not compete with private industry for work that industry could do, and observing this rule sometimes denied interesting work to Sandia. Under its work-for-others program, however, Sandia could offer its unique services, facilities, and expertise for reimbursable projects that did not interfere with its primary missions. For the first time, Sandia in 1989 offered its special expertise and experience to all potential bidders on a conventional ordnance package designed to detect and attack advanced airborne targets.

When the Motorola Corporation won the competition for this work, it entered into an agreement with Sandia to provide specialty services essentially as a subcontractor. "This doesn't necessarily mean that we'll be doing lots of projects by working for defense contractors," Max Newsom explained, "but it's just one more way that we will be doing business."

Sandia cooperated with Motorola to improve the Air Force's advanced medium range air-to-air missile (AMRAAM), a successor to the Sparrow missiles used since the 1950s. Randy King coordinated Sandia's efforts to improve the ability of AMRAAM to strike and disable the advanced aircraft of the 1990s. This required upgrading the target detection components, the warhead, and the electronic safing, arming, and firing systems. Sandia's principal concerns included systems analysis of the air targets of the future, electronics system design, and slapper detonators to protect against inadvertent explosions. Newsom explained that these adaptations represented a trend seen among the military services in an era of constrained budgets. "Because major weapon systems are becoming so sophisticated and costly," he pointed out, "the services are upgrading and improving the systems instead of designing entirely new ones."

By the end of the decade, Sandia had contributed significantly to advanced conventional weapon designs. Examples include anti-armor weapons, electronic fuzing, improved guidance and control, hydrodynamic codes and materials models. Sandia benefited in return through the refinement of its own technical base.

RESEARCH THRESHOLDS

Jack Wirth in 1986 declared that Sandia began each project by designing reliability and safety into each weapon, and accomplishing this made it imperative that Sandia "cultivate a whole technology base that draws from experts in many fields — semiconductors, materials, physics, chemistry, and others — who provide a basic understanding of how things work and why." Sandians plumbing these and related disciplines provided many innovations in weapon components and designs.

When IBM researchers stunned the scientific world in 1986 by identifying ceramic-like substances that became superconducting at higher temperatures than metal superconductors, it spawned a worldwide race to find more of these substances, understand them, and refine them for applications. Having the potential for transmitting electricity far more efficiently and generating intense magnetic fields, superconductors proffered opportunities for creating incredibly fast computers, magnetically levitated (maglev) trains, and exquisitely sensitive medical scanners. Sandians saw that superconductors might in time revolutionize electrical engineering, as ball bearings earlier had transformed mechanical engineering.

Discovered in 1911, superconductors are metals or ceramics that when frozen to near absolute zero lose all resistance to electric currents, making them ideal for the transmission or storage of electricity. Because early superconductors required costly liquid helium as a refrigerant, however, their applications were limited. The 1986 discovery of substances that became superconductors at higher temperatures permitted the use of liquid nitrogen, a cheaper refrigerant, perhaps making superconductors economically feasible. "It's easily the biggest breakthrough in any area of science I've worked on in my 25 years at Sandia," said Jim Schirber.

Because the dark side of a space satellite becomes quite cold, superconductors seemed potentially useful for energy storage in space, perhaps powering strategic defense weapons. Recognizing this and other possible applications, President Reagan in 1987 approved a national superconductor research initiative.

Charged with developing new weapons and with defending the United States against technological surprises, Sandia joined the search for materials that became superconductors at higher temperatures. "The purpose of our program is to develop a fundamental understanding of the physics of superconductivity in oxides and the processes required to form them," explained Irwin Welber, "and to apply that knowledge to the development of novel prototypic devices."

Sandia's superconductor research proceeded at an around-the-clock clip during late 1986 and 1987. By combining cuprate oxides, Sandia created materials that steadily raised the superconductivity threshold. Fred Vook stressed the significance of these advances, "What most scientists would have considered pie in the sky a few months ago is now a reality."

David Ginley of Sandia's superconductivity team emphasized keen scientific competition as an additional motivation for urgent research. "You were at hammer and tong with the rest of the world to see if you could get there first." The discovery of each new superconducting material prompted efforts at Sandia and elsewhere to grow crystals of the material, draw it into wires, or deposit it as thin, uniform films for use in electronics.

In 1988, when the University of Arkansas reported success in making thallium-based, high-temperature superconductors, Sandia focused on the thallium system. Richard Baughman, Ginley, and colleagues made the first superconducting thin film of this material that lost all resistance to electricity at minus 285° F — thirteen degrees warmer than earlier thin-film superconductors. Working from this advance, Sandia joined with University of Wisconsin researchers to produce superconducting flux-flow transistors that perhaps could be used in improved radar-signal processors. "We're not sure yet," said Paul Peercy, "but it could be the building block for a whole new family of electronics."

As urgency waned and science settled into a more sedate pace, Jim Schirber, George Samara, Roger Assink, Douglas Loy, and their associates turned their attention to buckyballs, a third major form of carbon (diamonds and graphite are the others) discovered in 1985 that had unique resilience, shape, and properties. Named for Buckminster Fuller because the shape of the carbon-60 molecule resembled the geodesic dome he designed, buckyballs doped with alkali became superconductors at temperatures higher than most other materials.

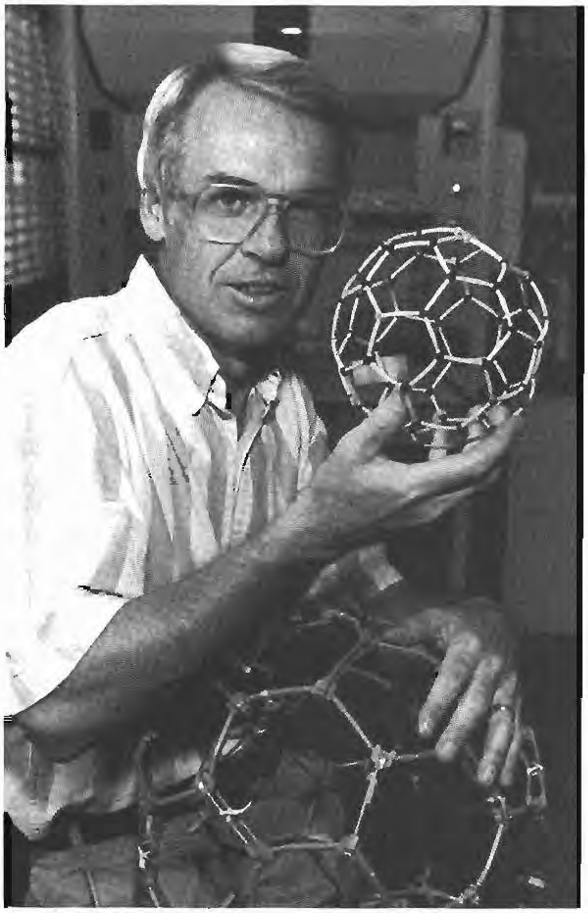
Sandia's team made polymers of the soccer-ball-shaped carbon-60 molecules, which might be used to form high-temperature seals. They also learned that buckyballs could store or filter gases. Oxygen molecules could pass through spaces between the carbon-60 molecules, while methane molecules could not; and this pointed toward the use of buckyballs for filtering impurities from natural gas or for other energy resource production. At the same time, another Sandia team composed of Paul Cahill, Craig Henderson, Kenneth Gillen, and Celeste Rohlfing explored the properties of carbon-70 molecules, sometimes described as shaped like rugby balls, and they became interested in using carbon-70 in high-strength and lightweight materials. Whether exploring superconductors, buckyballs, or rugby balls, Sandia sought to achieve fundamental understandings coupled with useful applications. This required expertise in physics, materials science, materials processing, custom designs, and testing, and as Paul Peercy observed, "Sandia is one of the few places in the world able to do all this."

MORE LIGHT

Before the 1980s, Sandia had ensured weapons safety through a combination of mechanical and electronic logic. But intricate mechanical mechanisms were expensive, and spurious signals might short circuit electrical wiring. As science and technology progressed, Sandia began shifting to new designs, linking optical, or photonic, systems with electronics.

Electro-optics, or photonics, appealed to weapon designers for several reasons. Replacing electric wires with fiber optics and using light rather than electric current circumvented the potential problems of

Gene Venturini, Jim Kwak, Bruno Morosin, Jim Schirber, and Dave Ginley in 1987 demonstrate a new superconductor material immersed in liquid nitrogen and connected to a battery and voltmeter. The zero reading on the voltmeter indicates the absence of electrical resistance in the superconductor material.



electrical and electromagnetic interference, thereby affording improved reliability and safety. Blocking the path of light seemed easier than using switches.

Photons, discrete packages of light energy, had been harnessed in lasers in 1960 and in fiber optics in about 1972. "Photonics represents a new technology," declared Jim Chang in 1985, "the next wave in a high-tech evolution that will create just as sweeping a change in our lives as has electronics." Chang led efforts at Sandia to develop a high-speed multichannel data recorder that combined a camera and photonic system to measure instantaneous events such as microwave pulses.

Using the strained-layer superlattice technology developed at Sandia in 1981, Del

Left: Roger Assink displays models of carbon-60 buckyballs, considered useful in gas filters.

Below: Kent Choquette of Sandia's photonics research in 1995 examines an enlarged microscopic image of the vertical-cavity surface-emitting laser (VCSEL) that was expected to revolutionize the manufacture of optical data links for computers.

Owyoung, Paul Gourley, Richard Schneider, and associates designed semiconductors for use in optically pumped lasers, meaning that the light from one laser powered another. They made a tiny laser capable of generating a vertical and visible light beam. "It's the first laser of its type to produce visible light," declared Owyoung. "With further development we foresee numerous applications for these devices." They might be used, for example, in new plastic fiber communications and optical printers.

As this research proceeded, Sandia's project teams applied more light to weapon designs. They adopted optical coupling across the exclusion region barrier for enhanced safety in one of their warhead studies. And in 1987 they began the still extant direct optical initiation program, an effort to design a firing set that used lasers to trigger weapon detonators.

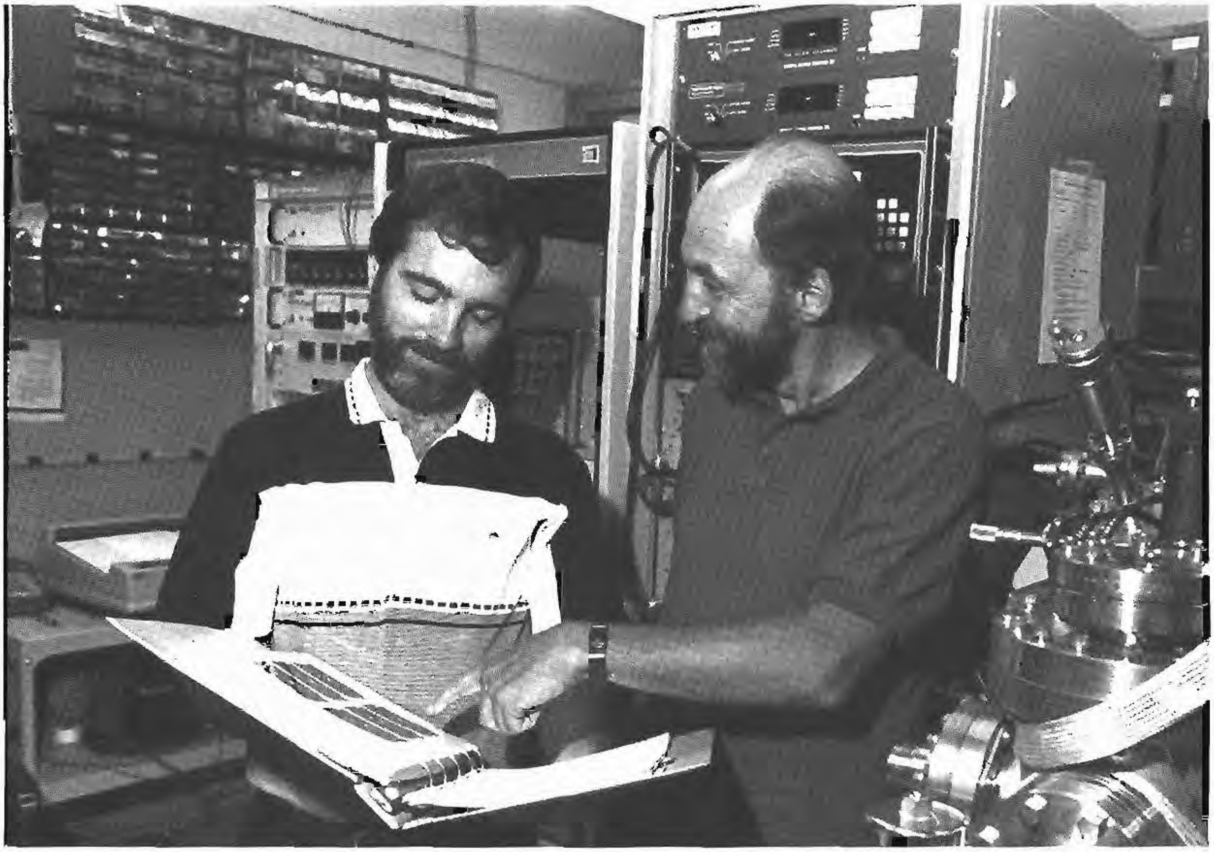
In the 1980s, Sandians also achieved significant advances in ion implantation, a means of altering the characteristics of metal alloys and other materials. William Shockley, co-inventor of the transistor at Bell Laboratories in 1948, discovered ion implantation in 1954. Used initially to zap silicon with the atoms of other elements to create integrated circuits that had thousands of transistors on a single microchip, ion implantation ushered in the era of electronic watches and pocket calculators. Beginning in the mid-1970s, scientists at Sandia were using ion implantation to alter metals and ceramics one atom at a time to create supertough, corrosion-resistant alloys and materials. In 1985, Tom Picraux declared, "The next few years will tell the tale on ion implantation."

Sandia built the Particle Beam Fusion Accelerator II (PBFA II), the most powerful ion-beam accelerator in the world, during the 1980s to conduct fusion energy research. Sandia also acquired ten smaller ion-beam accelerators for ion-implantation research. In vacuum chambers, beams of charged ions implanted such elements as nitrogen and carbon into the target materials, creating a thin layer of an alloy with properties different from the rest of the material. The target surface material was hardened but not distorted, and, unlike coatings, the new layer would not crack off. "You mix things that nature doesn't like normally," explained Picraux, comparing ion implantation to successfully mixing oil and water.

According to Picraux, Sandia's most significant innovations in the use of ions for materials analysis included hydrogen profiling by helium-elastic recoil detection, using ion channeling for materials analysis, ion beam analysis of components, and heavy ion backscattering spectrometry. Sandia became a world leader in ion beam analysis — hitting a material with an ion beam, causing reactions within the material to generate a variety of particles that could be detected and analyzed when they emerged from the material. This technology was useful for materials design and could even be used to identify materials as evidence in criminal investigations. Tom Picraux received the 1990 E. O. Lawrence Award for his pioneering research in the use of ion beams for materials analysis.

Using ion implantation, Sandians fired oxygen ions into aluminum, producing a stronger metal that was less subject to wear than common aluminum alloys and might be used to fabricate lightweight aircraft, spacecraft, or ground transportation. Ion implantation might also harden ball bearings, or produce artificial hip and knee joints sufficiently durable to outlast the patients in whom they were implanted.

Because thin films must be prepared one layer at a time, for microelectronics as well as for other "tailored materials" applications, scientists need an understanding of the mechanisms by which atoms spread out after deposition on a surface. This compelling issue was addressed by Sandia theorist Peter Feibelman through the use of a unique computational approach and the laboratory's supercomputing capabilities. An important result of his work was the prediction that on certain metal surfaces, atoms would not hop over ridges from site to site, but rather would incorporate themselves into the underlying metal while pushing a metal atom out onto the surface. In short order, this prediction was verified by field ion microscopist Gary Kellogg. Feibelman and Kellogg's results have



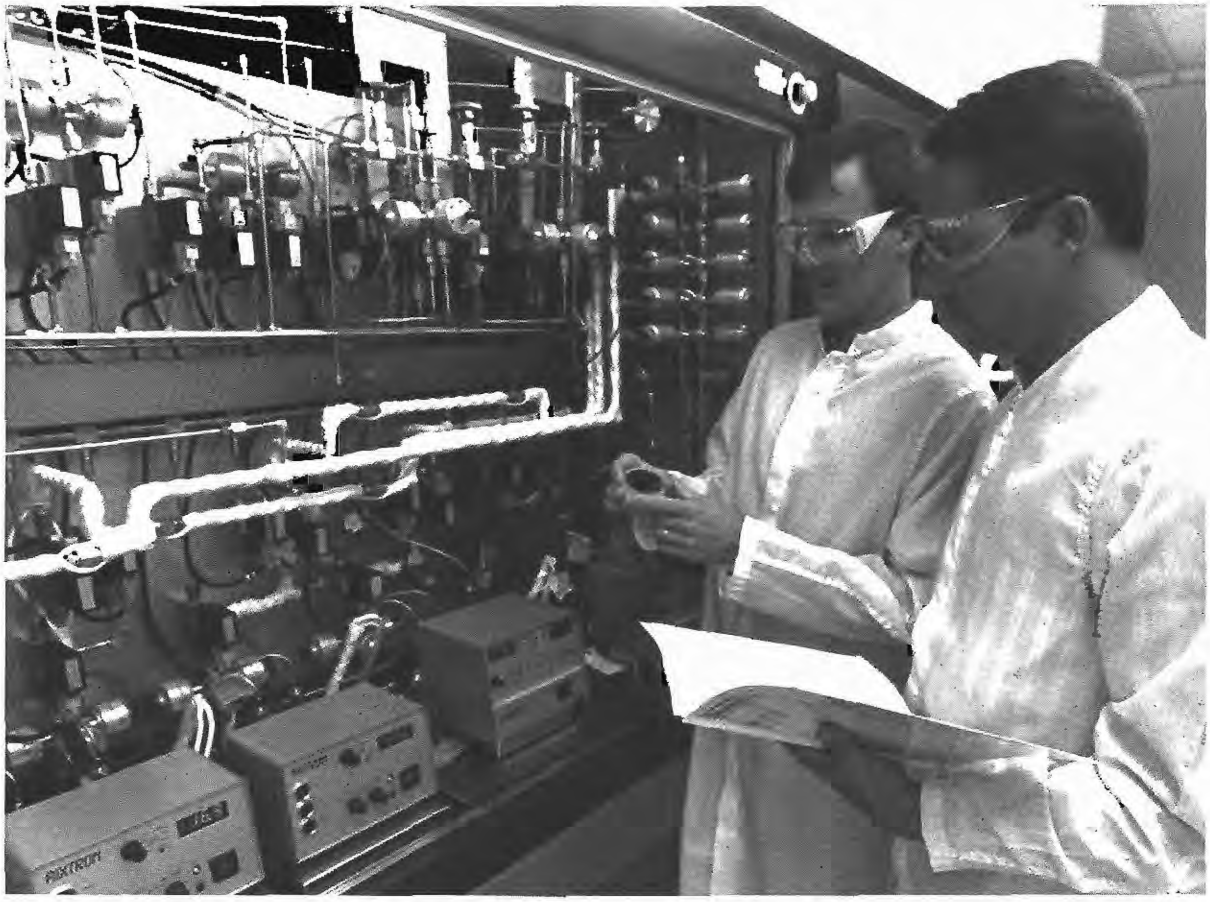
Gary Kellogg and Peter Feibelman of Sandia's surface sciences staff in 1991 examine field ion microscope images of atomic activities on surfaces.

changed the way scientists think about growing multi-component thin films, and may ease efforts to prepare unusually strong materials, highly reflective x-ray mirrors, and novel catalysts. "No longer do we merely wish to characterize the nature and behavior of materials," Feibelman declared, "we want to design and grow them for specific purposes."

With these and similar research findings, Sandia advanced its improvements to compound semiconductors, leading to a new era of Sandia photonics. Before the 1980s ended, it had devised memory chips for space satellites that could retain data without a power source, radiation-hardened optical switches, semiconductor-diode lasers generating optical signals, steerable laser arrays focusing a single beam, and infrared detectors based on strained-layer-superlattice technology that might be useful for SDI. Reflecting on these developments, Fred Vook asserted, "No technology is more important to both military and economic security than semiconductor electronics."

POWERFUL MATERIALS

Bob Eagan, Ed Beauchamp, and Frank Gerstle managed Sandia's efforts to improve specialty ceramics and glass for weapon applications, and they enjoyed notable successes, especially the corrosion-resistant glass dubbed TA23 that proved useful in battery improvements. After developing powerful lithium and sulfur dioxide batteries, Sandia learned that the lithium corroded the glass insulators separating battery anodes from cathodes, causing an electrical short. Sandia applied TA23 glass to resist the corrosion and thereby extended lithium battery life to ten years or more. Because TA23 glass could also withstand corrosive body fluids, the medical industry later adopted it to seal devices implanted in cardiac patients.



Rick Schneider and Jim Lott in 1993 work at the equipment used to grow wafers for use in fabricating a semiconductor laser they developed.

In 1988, Bob Graham and associates in Sandia's shock-wave group designed a radically different shock-activated battery for weapon or space systems. The device consisted of a porous yet solid electrolyte sandwiched between two plates. When a shock struck this battery, it compressed the electrolyte, converting it to a fluid in less than a microsecond. It had a twenty-year shelf life like earlier thermal batteries, but could be activated in microseconds rather than the seconds required by earlier battery designs. "Until now," Graham remarked, "we've never had a power source that you could turn on in this time frame that would persist over a relatively long period of time."

Other Sandians pursued research leading toward lightweight batteries made entirely of plastic. For years, Glen Kepler in collaboration with Bob Anderson, Steve Kurtz, John Zeigler, and colleagues led Sandia's research on conductive and piezoelectric polymers that found important applications during the 1980s. Used to make plastics, paints, films, and synthetic rubber, polymers were ubiquitous in American households of the 20th century. Late in the century, however, scientists found new polymers that could conduct electricity, that could emit light, that could release electricity when struck by a mechanical shock. "It's clearly revolutionary," Graham said of this advance.

During the 1980s, Steve Kurtz, Charles Arnold, and associates doped thin polymer films with chemicals to make them less susceptible to radiation-induced conductivity. Thin mylar films used in capacitors add safety because the polymer melts, shorting the capacitor during accidental fires. But pulsed radiation can free electrons and make the polymer conductive, rendering it useless for energy storage. Mica paper capacitors were used for radiation resistance, but they did not short out during fires. Sandia developed a new radiation-resistant polymer to meet both needs and planned to use it in the W89. Roger Edwards noted that had this radiation-hardened polymer been developed a decade before, it could have improved the safety of earlier weapon systems.

When searching for a polymer insulator that would neither char nor become conductive when exposed to fire, John Zeigler and Larry Harrah in 1985 found a polysilane that reacted to ultraviolet light. It occurred to them that this unique property made the material suitable for imprinting circuit patterns on silicon wafers for microelectronics. "These conductive plastics are exciting," said Zeigler, reflecting on the research, "because they may ultimately be useful in batteries which would be much lighter than current batteries and could provide more power for a given weight."

Tougher than leather, clear as crystal, and flexible as paper, the potential applications for conductive and piezoelectric polymers seemed endless. Because piezoelectric (from the Greek *piezein* meaning to press) vinyl polymer responded to shock and physical deformations by generating electric signals, it could become useful in such applications as microphones and satellite sensors.

With DoD funding, by the end of the 1980s Sandia had developed a piezoelectric plastic as an accelerometer for missiles. Consisting of the plastic and a tiny microamplifier mounted atop a metal bolt, it allowed anti-ship missiles to discriminate between the impact of a bullet fired at it and the shock of its hitting a ship's bulkhead. When sufficient shock compressed the film, it released a voltage signaling contact to the missile firing system. "It's a very simple device," said George Laguna of the Sandia components team, "We wanted to make this for five bucks."

Sandia also used piezofilm sensors in its devices for monitoring the seismic and shock waves of underground nuclear tests, and it continued exploring other applications. Research indicated that conductive polymer coatings could dissipate static electricity and reduce lightning-strike damages in weapons. With such materials available, lightweight batteries made entirely of plastic no longer seemed an unreachable goal.

This was one of five Sandia teams receiving DOE Basic Energy Sciences and Materials Sciences Awards in 1994. *Left to right:* Kevin Horn, Bruce Kellerman, Dan Buller, Arnold Howard, Jerry Floro, Tom Picraux, Tom Mayer, and Eric Chason received the award for metallurgy and ceramics research.

Publication of the findings of these and other research initiatives increased Sandia's reputation in the scientific community during the 1980s. Before 1980, for example, Sandia's only recipient of DOE's prestigious E. O. Lawrence Award for research excellence had been Tom Cook for his studies of nuclear weapon effects. In 1984, the award went to Gordon Osbourn for his strained-layer-superlattice theory, and Gus Simmons received the award in 1986 for his encryption code advances. For his ion implantation research, Tom Picraux earned the award in 1990, and it went to Pace VanDevender in 1992 for pulsed-power research. In 1996, Jack Jakowatz received the award for his work in processing synthetic aperture radar image data. Beginning in the 1970s and continuing throughout the 1980s and 1990s, Sandia played a prominent role in the DOE's Basic Energy Science (BES) Program under the leadership of Fred Vook, Dan Hartley, and George Samara. In materials sciences, Sandia became a frequent winner of BES awards. In addition, Sandians were elected to the prestigious National Academy of Engineering, including Al Narath, George Samara, Walt Herrmann, John Galt, Venky Narayanamurti, and Paul Fleury, while Burt Westwood and Bill Brinkman were elected to the National Academy of Sciences. Although these impressive achievements and awards heightened Sandia's visibility, Irwin Welber liked to remind people that Sandia was "not just another think tank."

NOT JUST ANOTHER THINK TANK

"The world cannot afford a Challenger disaster in our nuclear weapons programs," Welber warned a Senate committee when testifying on the need for intense attention to nuclear weapons safety. Orval Jones and other engineers carefully studied the reports on the Challenger space shuttle disaster of 1986. Jones postulated that the accident had resulted in part from the "can do" philosophy at NASA, an intensely schedule-driven approach to engineering shared by Sandia. In the wake of the disaster's sobering reminder that engineers should never become complacent, Jones and Sandia's weapons teams reemphasized "designing in the safety" and the independent auditing of weapons safety. "Just because it worked last time," Jones said in his analysis, "don't assume that it's necessarily safe."

In addition to troubling engineers everywhere, the Challenger accident, along with a concurrent series of expendable rocket explosions, caused a shortage of space transportation during 1986. Looking for a more affordable way to launch its space experiments, General James Abrahamson of the Strategic Defense Initiative Office called on Sandia to study more cost-efficient launching systems and to make available its Kauai test facilities and rocket experts to support SDI. "It is the first step in learning how to test these concepts," Abrahamson said, "and we attach great importance to it." Welber agreed that Sandia would provide these services, but warned that the urgent schedule might have to be adjusted in view of the risks if it were to be accomplished in an orderly manner.

Welber outlined Sandia's role. "We bring something unique to our work in SDI — when we do systems analysis, whether it's decoy detection or whatever, it's based on a knowledge of hardware. We have people who have built these things, measured them, and understand them physically, and they understand the physics involved. So when we make an analysis, it's not based solely on paper, it's based on experience as well. That's unique. It truly is. We're not just a think tank."

Sandia's launching facilities at Kauai were upgraded, and in 1986 Sandia, in cooperation with the MIT Lincoln Laboratory, launched sounding rockets to

Sandia smashed this rocket-assisted F-4 aircraft into a concrete abutment in 1988 to test the concrete, not the aircraft. Sandia sought to determine how concrete structures could protect nuclear reactors against an aircraft crash.

measure laser-beam propagation through the atmosphere. A Sandia control system pointed detectors aboard the rockets toward a ground-based laser throughout the flights while telemetry measured various means of maintaining laser-beam focusing through the turbulent atmosphere.

Sandia's countermeasures and survivability studies for SDI were, if anything, too successful in delineating the problems to be surmounted. Welber wryly observed that "countermeasures work does not get you kudos." On the other hand, Sandia's directed-energy experiments did bring it kudos from General Abrahamson. Sandia completed its Hermes III and Saturn particle accelerators on schedule in 1988 and at the predicted costs. At its EPOCH accelerator, Sandia proved it could send a stable electron beam along a laser channel for long distances, and the FALCON reactor-pumped laser research showed progress in spite of beam divergence. "Our work covers the whole SDI cycle from threat studies to development of rocket hardware and instrumentation, from system studies to physics investigations," Jones declared.

As part of its countermeasures assignment, Sandia undertook to develop techniques for distinguishing between real warheads and decoys and to provide earlier detection of missile launches. At Sandia's combustion research center, for instance, a team including George Schils, Donald Sweeney, and Ellen Ochoa found ways to use three-dimensional holograms produced by laser beams to image and recognize the plumes of rockets during launch. Ochoa later joined NASA and became an astronaut aboard the space shuttle Discovery in 1993.

Missile defense systems had three chances to destroy warheads: when missiles rose into space, as they traversed space, and when they reentered the atmosphere. Sandia's concept involved intercepting missiles during the second phase. "The idea is to combine a kinetic-energy kill with a directed-energy beam to discriminate warheads from decoys," explained Pace VanDevender. "We think this has the potential of being cost-effective and doable and very difficult to counter." Kinetic energy weapons, such as "smart rocks" or "brilliant

Left to right: Pat Falcone and John Crawford accept a memento of the 1993 space shuttle Discovery flight from NASA astronaut Ellen Ochoa, a former Sandian.

A Sandia STARS missile prepared for launch at the Kauai Test Facility. It was a modified Polaris missile equipped with a Sandia flight computer and a Honeywell inertial navigation unit for guidance.

pebbles" that destroyed missiles through high-speed collisions rather than explosions, could follow directed-energy beams to target incoming missiles.

The "smart rocks" concept envisioned small missiles with on-board computers and sensors to detect incoming missiles, then smash into them at velocities high enough to punch holes through them. "Brilliant pebbles," smaller than "smart rocks," became part of SDI planning late in the Reagan administration. These tiny rockets, weighing merely a hundred pounds and controlled by miniature supercomputers, could hurl projectiles — pebbles — at missiles in flight. Because of their light weight, brilliant pebbles could substantially reduce the costs of deploying an SDI system into space.

Sending hundreds of kinetic hypervelocity launchers into space at affordable costs required reductions in launcher weight, size, and power requirements, or finding a means other than rockets of boosting them above the atmosphere. Joining in explorations of the latter technology, Sandia began fascinating experiments with electromagnetic launchers.

While researchers elsewhere experimented with electromagnetic railguns, in which electricity passing between two rails fired a projectile from a cannon barrel, Sandia, with SDI funding, experimented with a coil gun as a potential hypervelocity device to fire brilliant pebbles into space. In coil guns, the projectile never touched the cannon barrel. Two isolated magnetic fields interacting serially pulled the projectiles forward at exponentially increasing speeds.

This hypermagnetic power technology led to reimbursable studies of its use in firing conventional artillery shells and, during the 1990s, to interest in using it to propel fast trains on railroads. Called SERAPHIM (segmented-rail phased-induction motors) this system was promoted by Bob Turman and Barry Marder as an alternative to the better known magnetic-levitation technology based upon superconducting magnets. Sandia's studies indicated its coil gun induction motors could pull trains along at 300 miles per hour, limited only by the condition of the rail tracks and air resistance, while providing passengers with a more comfortable ride as well.

By 1988, Roger Hagengruber of exploratory systems explained that the SDI thrust had shifted from long-range directed-energy research and space-based weaponry to a ground-launched system defending U.S. forces against accidental missile launches, or even surprise launches by a non-superpower. By that year, Sandia's SDI support concentrated on the experimental test launches called Starmate, and later on the strategic target system (STARS) sponsored through the Army Space and Strategic Defense Command.

In support of STARS, Sandia utilized surplus Polaris A3 missile assets to design a new three-stage missile configuration to deliver targets (reentry vehicles) from the Kauai Test Facility to the Kwajalein Missile Range, an intermediate-range ballistic missile distance, with ICBM reentry velocity. A new third stage motor was developed and combined with state-of-the-art guidance, control, sequencing and monitoring systems to provide enhanced performance, safety, and reliability. The modified Polaris missiles used Sandia's small SANDAC V supercomputer coupled with inertial navigation systems for guidance and flight control. Eric Schindwolf, manager of Sandia's STARS program, noted that the first STARS launch carrying both American and British experiments deliberately damaged the heat shield of the reentry vehicle to determine its survival abilities during reentry. If funding permitted, up to forty additional STARS launches were planned during the 1990s and beyond.

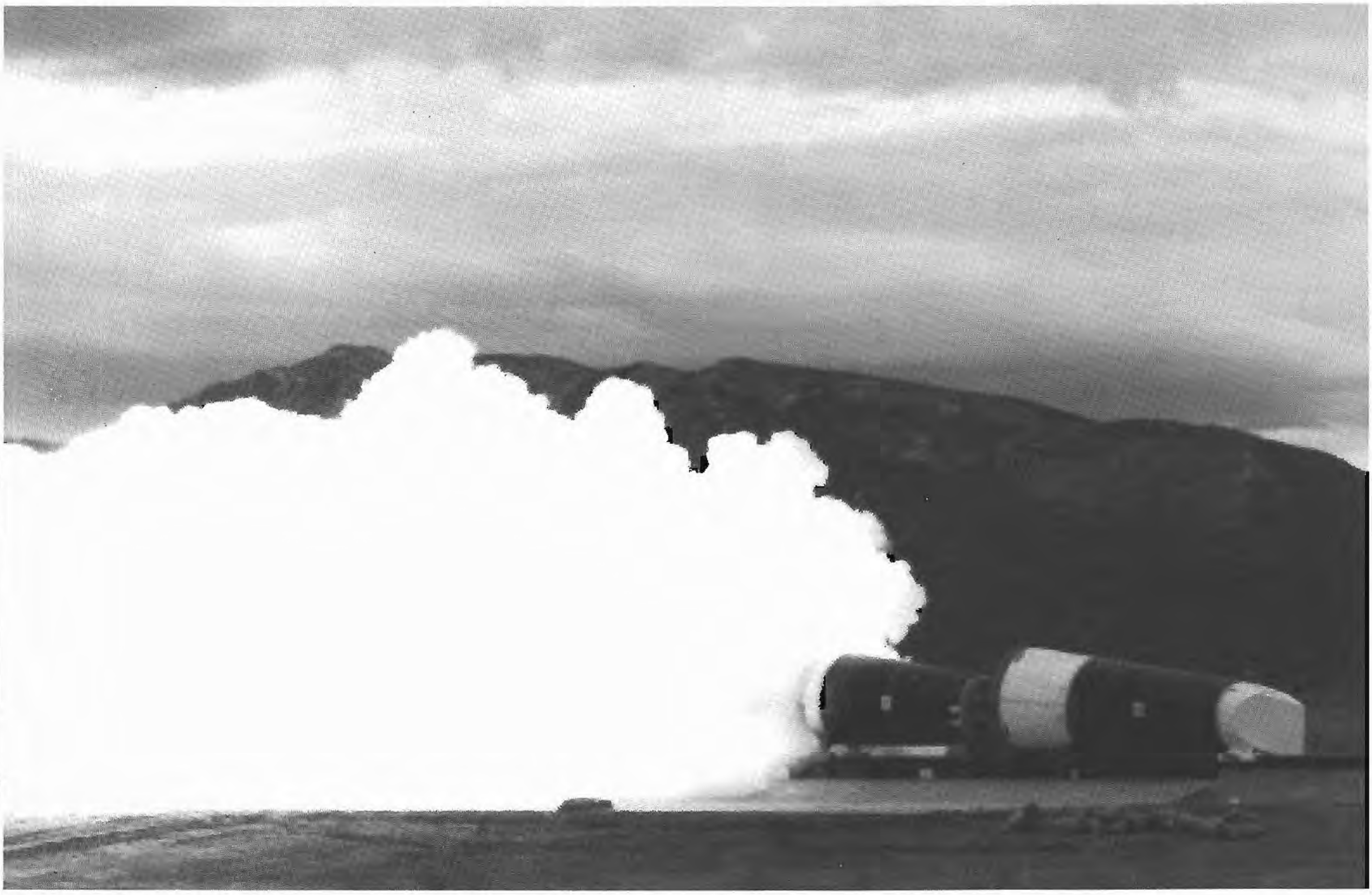
Disturbed by bitter divisions among scientists and in Congress over the SDI programs, Hagengruber worried that pressure for early, tangible results might warp SDI experimentation. The polarizing debate among scientists seemed also to threaten public faith in science, Hagengruber warned, adding, "When we go to war over technology in national defense, the first casualty for the scientific community is credibility."

To Gerold Yonas, who returned to Sandia in 1989 after service with SDIO and in the private sector, it seemed that many people misunderstood the fundamental value of SDI research. "The knowledge base is the real commodity, not the weapon," he said. "People miss the point when they emphasize widgets."

TRUST BUT VERIFY

Whatever the point of SDI, it gave Soviet leaders additional incentives to return to the bargaining table with serious proposals for arms control. Providing technical advice in Geneva and Washington during these negotiations were Sandians such as Clyde Layne and Stan Fraley. Their efforts contributed to successful negotiations leading to the Intermediate-range Nuclear Forces (INF) treaty signed in late 1987.

When signing the INF treaty, President Reagan declared it the first in history to "rid the world of an entire class of nuclear weapons" and pledged it would be only the first step in a quest to end the nuclear arms race. The treaty specified the destruction of intermediate-range missiles deployed in Europe. This included the Pershing intermediate-range missiles armed with the W85 and the ground-launched cruise missiles armed with the W84, which were two of the most modern and safest of nuclear warheads in the arsenal. The INF treaty also had unprecedented provisions for verification, such as on-site inspections of plants that manufactured the prohibited missiles. "Trust but verify" became President Reagan's watchwords for future negotiations, and to support verification efforts he and Congress



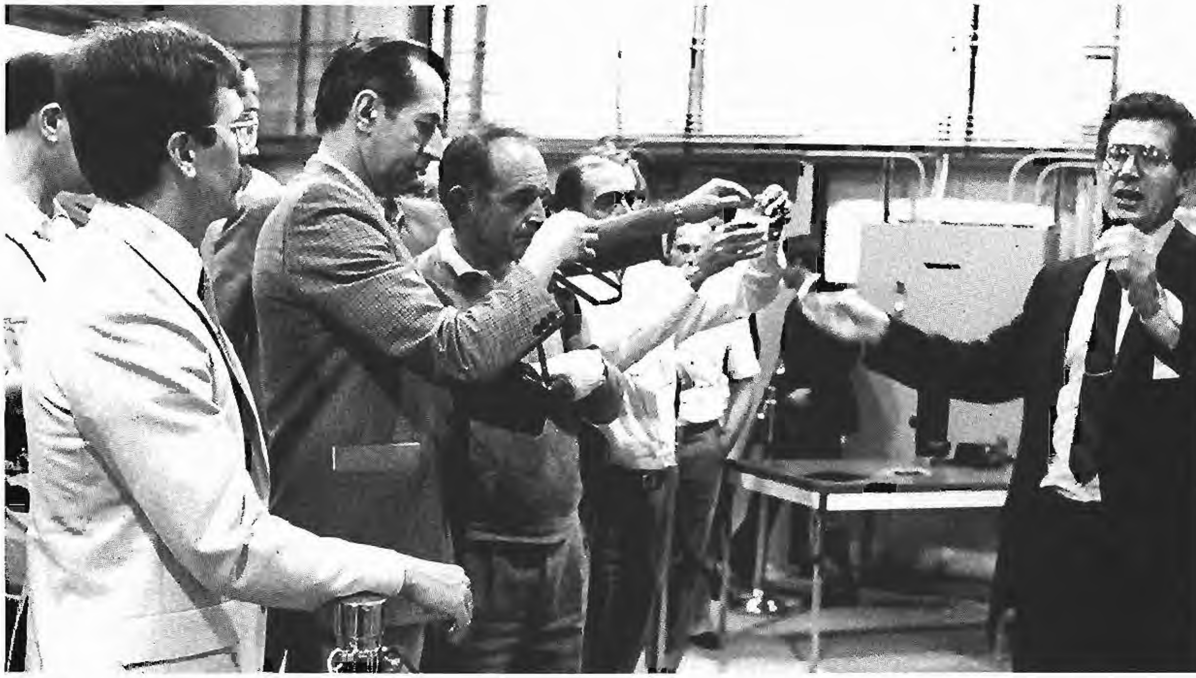
One of the fastest vehicles ever sent down Sandia's sled track was this two-stage Sprint rocket. Tested in 1987, it was an experiment for the Strategic Defense Initiative.

provided substantial new funding for verification and control technology development.

Roger Hagengruber declared that Sandia's influence on the treaty negotiations came as a result of its impartial, dispassionate, and extremely reliable technology developed to monitor adherence to earlier treaties. "It's not hot air; it's performance and a product," he said, concluding, "In this area, resourceful engineering and historical insight have made technology a catalyst for progress."

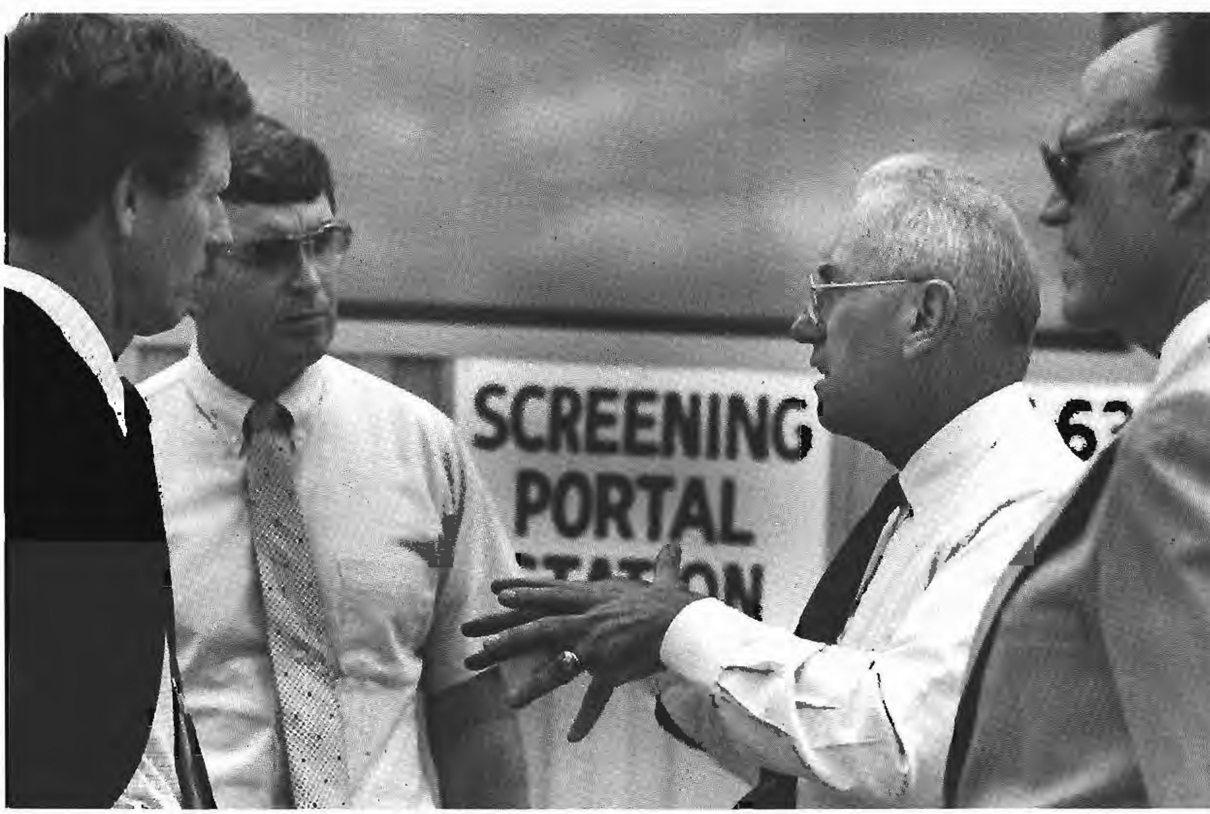
Sandian Stan Fraley led the Geneva team that drafted and negotiated the INF treaty's inspection protocol. Don Bauder, John Taylor, and Pauline Dobranich at Sandia backed him with verification capabilities data. When Fraley presented the protocol to the Soviets, he expected them to study it for months. "Instead, about a week later, they agreed to establish a joint working group to produce a joint draft," Fraley recalled, and "at the first meeting of the joint working group, the head of their side said that instead of countering with their own draft, they would work from the U.S. draft. That's when I began feeling they were really serious."

Based on the findings of an earlier Defense Science Board Panel, which included Hagengruber as well as former Sandians Ted Gold and George Look, rocket monitoring was selected as one of the approaches to be taken in verifying compliance with the treaty. During 1986, Sandia rushed the completion of a technical on-site inspection (TOSI) demonstration and test facility to



Stan Fraley, *right*, in 1987 explained Sandia's technology for verifying arms control treaties to visitors from NATO.

Paul Stokes, Roger Hagengruber, and Arlyn Blackwell listen to Admiral Foley of DOE's Division of Military Applications, *center*, discuss the Technical On-Site Inspection facility during his farewell tour of Sandia in 1987.



FROM WATCHMEN TO SWAT

MPs checking cars entering Sandia Base in the early 1950s.

Security Organization

The security program at Sandia has gone through several distinct stages during the Labs' history. In fact, during Sandia's first few years of operation, security was provided by the U.S. Army Military Police (MP). Some older retirees recall being challenged by MPs in the tech area and having to place their badges on the ground and step back while the guard checked the badges.

In 1950 Sandia agreed to take over security and created a 150-man guard force. The guard force was essentially the focal point of the program and was, like all the AEC guard forces of that time, a team of armed watchmen. Other administrative aspects of security, like classified document and nuclear material control, were evolving as the AEC generated orders for different activities. The first female guards were employed at Sandia California in 1972 and New Mexico followed suit in 1974.

The security program evolved somewhat over the next 25 years, but essentially remained an industrial security-based activity until the early 1980s (i.e., guards armed with light sidearms whose duties were basically those of watchmen). At that time a number of terrorist attacks on U.S. military and civilian targets occurred around the world, and concern for the protection of nuclear material increased sharply. With that, the Sandia security program was drastically changed (as was true at all DOE installations). Physical fitness standards for armed security personnel were imposed, weapons were changed to include fully automatic firearms, and training was greatly intensified. For the first time special weapons and tactics (SWAT) teams were formed. Sandia's SWAT team, called STOP — for Special Tactical Operations Personnel, was formed in 1983. By 1995 these teams were more commonly referred to as SRTs, or Special Response Teams. The "industrial guard" concept at Sandia essentially disappeared as these highly trained, para-military units were created. Changes to the security forces at the California site and Tonopah Test Range were similar in nature except that California has no special response teams because higher categories and quantities of special nuclear materials are not stored there.

In the 1990s, Sandia underwent other changes as security needs and budget impacts were more directly connected. More technology in the form of automated access control points was brought into use as a substitute for, and an enhancement to, the use of armed personnel. More sophisticated technology is being increasingly used as the foundation for the security program as Sandia prepares for the security challenges of the 21st Century.

illustrate capabilities for monitoring the movement of missiles into or out of a production plant. In just three months, Don Bauder, Dave Gangel, John Holovka and their Sandia engineering force completed TOSI, including utility systems, concrete pads, a mile of fencing, mobile offices, intrusion alarms, video and communications systems, and railroad tracks. It had a sensor network to establish that vehicles leaving a monitored site were not carrying the rocket motors prohibited by the treaty.

President Reagan personally viewed a scale model of this facility, and in early 1988 Soviet scientists and negotiators visited Sandia and inspected TOSI. Upon completion of his visit, the head of the Russian delegation told Hagengruber, "If any of my colleagues still have doubts about the availability of technology for monitoring this treaty, I shall disabuse them of it!"

Aircraft transported TOSI hardware from Sandia to the Soviet Union in 1988 for installation at the Votkinsk missile plant, and Sandian Frank Martin, accompanying the TOSI equipment, was aboard the first American military plane since World War II to enter Soviet air space unaccompanied.

Sandia received commendations from high levels for its TOSI efforts. Secretary of Defense Casper Weinberger, for example, complimented Sandia's completion of scale models and the full-scale facility on the demanding schedule required to brief the President, his Cabinet, and the negotiators in Geneva. "We consider such an effort to be an exceptional contribution to the security of our nation," Weinberger concluded. Another Defense official, Richard Perle, remarked, "The national laboratories are the gems in the technological crown of the country."

At the 1988 Moscow Summit, Reagan and Gorbachev reached agreement on joint verification experiments to test the technology for detecting and determining the yields of underground nuclear tests. This was needed to see if the two countries could work within the 150-kiloton testing limit set by the Threshold Test Ban and Peaceful Nuclear Explosions treaties negotiated during

Orval Jones escorts Senator John Glenn during his 1988 inspection of Sandia's verification and control technology capabilities.

the 1970s. The collaborative experiments, which would eventually lead to substantive technical collaborations in the 1990s, first involved an exchange of visits to each nation's testing sites, followed by deployment of equipment to the sites, and finally participation in joint test and yield verification.

The first joint verification experiment took place at the Nevada Test Site in August 1988. Paul Stokes, Carter Broyles, and other Sandians participated in this test that would have been unimaginable a few years earlier. Paul Robinson, the U.S. Ambassador heading the Geneva negotiation team and a future president of Sandia, and Horace Poteet of Sandia were among the delegation present at Semipalatinsk for the Soviet nuclear test in the autumn of 1988. By the time of these joint verification tests, Sandia had a broad spectrum of research on verification and control technologies underway. Senator John Glenn and Presidential science advisor William Graham visited Sandia in 1988 to review its research, chiefly its studies of "tagging" — affixing indelible "fingerprint" identifications on weapons. Welber said the visitors went away satisfied that Sandia had developed exceptional tagging capabilities.

The tagging concept espoused by Don Bauder envisioned placing unique and unalterable tags on treaty-limited equipment for comparison with tags found during subsequent on-site inspections. Sandia produced two types of tags: reflective-particle tags and electronic tags. The reflective-particle tag consisted of clear plastic and crystalline particles painted onto an item. The random distribution of the particles created unique patterns that could be recorded and verified at later dates. The electronic tag consisted of a small integrated circuit bonded to a weapon, providing a license number that could not be altered or reproduced. When interrogated, this tag responded with a self-identification. It could also be interrogated remotely, allowing distant monitoring of the whereabouts of treaty-limited items.

By the end of the decade, Sandia had the largest verification and control research program in the nation. About six percent of its technical staff had been assigned to the program, and an increasingly demanding workload was expected because the President had committed to accelerated negotiations at the strategic arms reduction talks (START). Welber saw this initiative as a sharp turn from the past that "will have profound effect on Sandia and on the stockpile." He predicted the resulting changes would demand greater flexibility of the Laboratories in the future.

WISDOM OF SOLOMON

"Technology transfer, sponsored and paid for by government funds and transferred to industry, is a paradox," Welber observed in 1986. "To be effective it must be proprietary and transferred to a specific company. That means you've got to exercise the wisdom of Solomon in picking out that company."

Sandia's efforts to transfer its technology to industry and business for commercialization had begun during the 1960s under Corry McDonald's management, succeeded in the 1980s by Bob Stromberg and later by Glenn Kuswa, Dan Arvizu, and Warren Siemens. Growing emphasis on technology transfer at Sandia during the 1980s originated not from the long-standing confrontation with the Soviet Union, but rather from national perceptions that economic challenges from elsewhere should concern the government. "The U.S. is seeing increasing industrial competitiveness from overseas," explained Kuswa in 1986, and "people are worried that our technological edge might be eroding."

National concerns about enhancing American competitiveness in global markets by transferring the government's scientific and technological capabilities to industry focused initially on assisting industries thought strategically valuable for national security. Among these were the semiconductor manufacturing and specialty metals industries that produced materials vital for weapon and space applications. "A healthy, competitive semiconductor industry is vital to the United States' national security in the broadest sense," said research vice president Venkatesh Narayanamurti, explaining to Welber why Sandia should become involved. "A principal problem afflicting the U.S. semiconductor industry is its failure to translate research initiatives into manufacturing advantages. This is an area where Sandia can help."

In 1986 the National Academy of Sciences urged Sandia along with Oak Ridge, Brookhaven, and Lawrence Berkeley laboratories to initiate research in cooperation with the domestic semiconductor industry. In 1987 President Reagan issued an executive order for the laboratories to respond to national concerns about the position of the United States in international markets. Reacting to this, Secretary of Energy John

Robert Perry displays a flask of crystals used for RAPRENOx (rapid reduction of nitrogen oxides), a process he discovered. By removing nitrogen oxides from diesel exhaust fumes, the process could foster cleaner air.

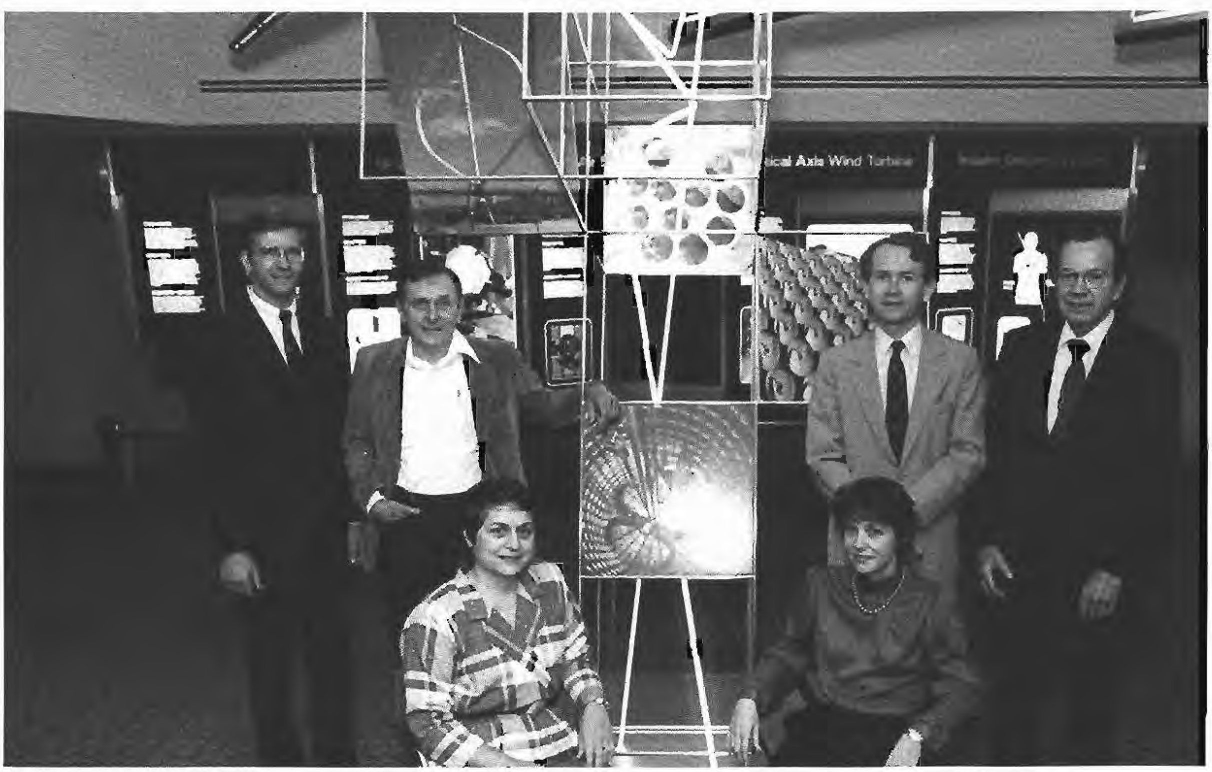
Herrington bluntly told Sandia, "Technology transfer opportunities should be fully pursued. Increased exchange of information between laboratories and industry should be encouraged. Improved relationships between the national laboratories and the universities of the Nation should be fostered."

At this juncture, the government joined with the domestic semiconductor manufacturers to form SEMATECH, a consortium with the goal of recovering world leadership in semiconductors and assuring the long-term health of the industry. Because semiconductor-based microelectronics were critical to weapon systems, and Sandia had existing facilities for their development, Welber, Jones, and other managers in 1987 sought to persuade SEMATECH to select Sandia as its headquarters. Although this initiative failed, Sandia established close relations with SEMATECH, cooperating in efforts to improve microelectronics fabrication equipment, assure the quality of microelectronics components, and explore environmentally responsible processes for producing integrated circuits. This relationship grew closer during the 1990s when former Sandian Bill Spencer became SEMATECH's president.

Narayanamurti, Larry Anderson, and Fred Vook proposed formation of a center for compound semiconductor technology and other centers specializing in microelectronics development at Sandia. Senators Pete Domenici and Jeff Bingaman of New Mexico arranged federal funding for facilities to house these new centers in 1988. To facilitate cooperation between Sandia and industry, Dick Schwoebel proposed that Sandia's microelectronics facilities be located outside the fences. "The technology interchange function that is an intrinsic part of this concept is best carried out," Schwoebel said, "not by obtaining clearances for or escorting outsiders into the technical area, but rather by developing appropriate unclassified facilities in which joint programs can be conducted with industry and also universities and other laboratories."

Bob Peurifoy, then Sandia's vice president for technical support, enthusiastically endorsed the concept of placing technology transfer facilities outside Sandia's classified and fenced areas. Indeed, he proposed the creation of a "microelectronics park" on the east side of Sandia in Albuquerque. Thus began the construction of the laboratories and office buildings that rose on Sandia's eastern flank during the 1990s.

Sandians Tom Picraux, Bill Brinkman, and Walter Bauer display a 1986 National Research Council report on the U.S. competitive posture in electronics materials processing.



Technology transfer received new emphasis at Sandia in 1986, when this technology transfer and patents team met. *Seated,* Teri Ripi and Pam Goldberger. *Standing from left:* Kurt Olsen, Joe Szymanski, Glenn Kuswa, Bob Stromberg.

It is noteworthy that the impressive growth of Sandia's technology transfer programs during the 1980s came largely as a result of national efforts to shore up strategic industries thought vital to national defense. Conversion of this program into a broader vehicle transporting Sandia's weapons expertise into the peacetime marketplace came during the 1990s, largely in response to the National Competitiveness Technology Transfer Act of 1989 sponsored by Senators Domenici and Bingaman.

A GENERATIONAL THRESHOLD

"Our laurels will only support us one year at a time," Orval Jones warned near the end of the 1980s. To which Irwin Welber retorted, "Our purpose is to serve national needs, not preserve ourselves."

Sandia had served many national needs during the decade. It engineered safer nuclear weapons with greater delivery flexibility for the armed services and provided significant support for Strategic Defense Initiative research, development, and experimentation. The technologies developed at Sandia for these programs also proved applicable to innovative designs for safer and more reliable conventional weapons as well as unconventional mobile robotic weapons and reconnaissance craft.

Its scientific acumen, especially its ability to apply science directly to tangible products, brought it national recognition and positioned it to respond to the public perception that strategic industries deserved assistance in economic competition through technology transfer. Its capabilities proved technically critical as well in the international negotiations leading to arms control and testing verification agreements — to ending the Cold War.

Perhaps Welber's biggest regrets lay in the energy arena. Funding for Sandia's energy research during the 1980s dropped by half, from thirty percent down to fifteen percent of Sandia's total budget. "I think we have an excellent weapon program, and our national security is protected well," Welber asserted in his farewell address, "but we really don't have an energy policy in this country."

Observing that some of the most modern nuclear weapons had been eliminated by the INF treaty and that more would go under the proposed START treaty, Welber focused on the national need for ensuring the reliability of a stockpile containing many weapons introduced a quarter of a century earlier. Achieving understanding of the aging processes posed a difficult challenge for Sandia in the future, especially as the veteran engineers who had designed them and monitored their condition in the stockpile reached retirement age.

"A new generation of Americans, a generation that was not seasoned by World War II and the Cold War, a generation that has been trained to ask questions, is now poised to assume leadership roles at Sandia and elsewhere," Welber observed. "If members of that generation are to perform their vital roles in the nation's defense, they must be more than intelligent and educated," he concluded, "they must be better informed about what we do, how we do it, and — most important — why we do it."

Irwin Welber meets in 1986 with Senator Jeff Bingaman and Representative Manuel Lujan of New Mexico.

IX

THE COMPETITIVE EDGE

The defining challenge of our age is to win the new economic competition, to make sure that in the 21st century America remains not just a military superpower, but an export superpower and an economic superpower.

George Bush

As 1989 unfolded, Americans marveled at the unraveling of East European communism, the demolition of the Berlin Wall, and the nomination of Soviet leader Gorbachev for the Nobel peace prize. Sandians were no less astonished at these historic events than anyone else. It was a year of political change in the United States as well. George Bush became President and selected James Watkins as his Secretary of Energy. At Sandia, Al Narath became the Laboratories' president. In 1989 Sandia and the nation, as Sandia's new president proclaimed, "crossed the threshold of a new era of change."

When environment, safety, and health concerns forced suspension of nuclear weapon production in 1989, Secretary of Energy Watkins urged close attention to these concerns, mandating sweeping cultural

Irwin Welber welcomes Al Narath upon his return to Sandia in 1989.

changes within his department and its laboratories. Sandia implemented these initiatives along with the Bush administration's expanded emphasis on energy research and bipartisan programs for economic competitiveness approved by the National Competitiveness Technology Transfer Act of 1989.

By 1989 Sandia had also achieved recognition as an excellent source of independent expertise. Congress, military services, and federal agencies called on Sandia for independent studies. On the other hand, Sandia, like other DOE installations, found itself under independent "tiger team" investigation of its environment, safety, and health priorities.

During the early 1990s, Sandia used its enormous nuclear weapon-based research foundation to hone its competitive skills in energy programs and on efforts to improve the national competitiveness posture. The transfer of Sandia's technology to the private sector, mandated by Congress, President Bush, and Secretary Watkins, proceeded at the quickest possible pace. In the midst of meeting these challenges, the surprises kept coming. Less than a year after the fall of the Berlin Wall, the United States was at war in the Persian Gulf and the military services urgently requested Sandia's technological assistance. And the following year, after forty-four years of service, AT&T announced it was ending its chapter of Sandia's history. Clearly, the cumulative effects of these events thrust Sandia into new and unexplored territory.

COMPETITIVE ENVIRONMENT

When Irwin Welber retired in early 1989, Al Narath returned to Sandia as president. Narath was a Sandian who spent five years at Bell Labs. After earning degrees from the Universities of Cincinnati and California Berkeley, Narath joined Sandia's solid-state physics research team in 1959 and rose to become executive vice president before transferring to AT&T Bell Laboratories as vice president for defense programs. "I had the

Gerry Yonas welcomes Secretary of Energy James Watkins to Sandia in early 1990.

Orval Jones, Al Narath, and Lee Bray, Sandia's top executives during the early 1990s.

advantage of living through five years of struggle at AT&T," he said, "which almost overnight was thrown into a dynamic, competitive environment and had to make many adjustments, some pretty painful, to survive in it."

In 1984 AT&T had begun its transition from a regulated monopoly to a participant in competitive free enterprise. "I came to the realization that technical excellence alone is not enough," Narath said of his experience at Bell Labs, "rather, it is teamwork and the ability to adapt quickly to changing operating conditions that spell the difference between success or failure in a competitive environment." Upon his return to Sandia, Narath implemented his two-part agenda: strengthening ties with AT&T and changing Sandia's culture to make it more responsive to shifting national priorities. "We come from a culture in which we always believed we knew best," he said. "We're moving into a culture where a significant fraction of our customers can take their business elsewhere — and will — unless they believe that Sandia offers them a better deal."

Narath orchestrated numerous changes to prepare Sandia for the opportunities of the future. To better address customer demands, he established three business sectors with Roger Hagengruber responsible for Defense Programs, Dan Hartley for Energy and Environment, and Gerold Yonas for Work-for-Others. To broaden application of the project-oriented approach pioneered in reimbursable programs, he appointed Herman Mauney as chair of a committee formed to empower project managers to negotiate schedules and costs. Streamlining this process and improving communications could increase customer satisfaction. "Just as the country's going to have to learn to compete in a world market," remarked Mauney, "Sandia is going to have to learn to compete in a broader market."

In January 1989, Glen Cheney introduced a total quality program to his component development vice presidency. Stressing both personal and corporate values, the total quality program focused on improving design quality to overcome difficulties experienced by manufacturers. Taking his cue from AT&T and the Defense and Energy departments, Narath expanded the quality program to all of Sandia later in 1989. As part of this change, Sandia's executive staff became the Sandia Management Council and later, with membership modifications, the Sandia Quality Leadership Council.

"The future is exciting, and together we will create it," Narath announced when launching Sandia's strategic planning in 1989. Although Sandia had written annual long-range plans for twenty years, these assumed little change in the external world. Strategic plans, on the other hand, considered future discontinuities of the sort that amazed the world in 1989. Published in 1990 as the first corporate strategic plan within DOE, Sandia's plan emphasized changing its corporate culture to embrace new world conditions. "More will be expected of us in the future," Narath predicted, "and we will be expected to do it with less."

Another thrust sought to identify Sandia's special core competencies and capabilities, the "discriminators" that set it apart from its competition. Paul Robinson, Sandia's laboratory development manager, offered this analysis: Sandia satisfied critical national needs for four primary reasons — it had a proven ability to organize and complete complex and time-critical projects, and it possessed large special-purpose facilities unavailable elsewhere. Third, its vertical integration fostered flexible response, rapid prototyping, and a tradition of managing weapons from cradle to grave that could apply to other programs. Fourth, although contractor-managed, it was part of government, with appropriate access to government information. Other discriminators

Gerry Yonas points out a satellite model feature to his work-for-others staff. *Left to right:* Bill Alzheimer, Jack Walker, Yonas, James Kelsey, Max Newsom, Don Rigali, Tom Sellers, Ron Andreas.

included its ability to undertake classified work and its weapon-program heritage of making applied science lead to tangible payoffs. Congress and outside agencies commonly took advantage of these special capabilities, for example in the request for an analysis of the battleship *Iowa* explosion.

INDEPENDENT INVESTIGATIONS

When Congress and federal agencies request institutions to undertake independent investigations of subjects not directly relating to their responsibilities, they indicate established trust in these institutions' capabilities and reputations. Judged by this index, Sandia achieved top status in 1989.

In 1989 William Graham, the President's science advisor, called Narath to request that Sandia join other DOE laboratories in investigating claims by researchers from Utah of success in achieving "cold fusion," or fusion at room temperature. If true, this discovery offered inexpensive alternatives to "hot" fusion, the inertial confinement approach of Sandia and several other facilities, and the more common magnetic confinement approach at other laboratories. But neither the Sandia team of Jim Schirber, Mike Butler, Dave Ginley, and Ron Ewing, nor other investigators around the nation, were able to confirm the Utah researchers' findings.

In response to another request, this one from the Senate Armed Services committee, in late 1989 Sandia investigated the causes of an explosion aboard the battleship *Iowa*. Early reports on the explosion, which killed forty-seven sailors loading one of three sixteen-inch guns in a turret, indicated a chemical igniter might have been used to sabotage the loading. Sandia at first rejected a request from the General Accounting Office to lead an independent investigation of the accident because the request included forensics, a science not among Sandia's core capabilities. When a request restricted to Sandia's expertise came from Senators Jeff Bingaman and Sam Nunn of the Armed Services committee,

Karl Schuler and Paul Cooper examine the drop-test setup for their investigation of the 1989 explosion aboard the USS *Iowa*.

however, Narath acceded, appointing Dick Schwoebel to head the investigating team.

Schwoebel first met with Navy investigators on December 7, 1989, and this led to a visit aboard the USS *Iowa* by Schwoebel, Mark Davis, Paul Cooper, and Dennis Mitchell. Schwoebel and Davis took a large number of swipe samples in the forward turret of the *Iowa*. Analysis of these and other samples by Jim Borders, John Holovka, and associates at Sandia found no conclusive evidence proving the use of a chemical igniter. In fact, the Sandia studies demonstrated that all the foreign materials identified by the Navy were common to the turret and could not be definitely related to the presence of a chemical igniter.

Observing that the rammer chain jammed powder bags against the base of shells in the gun's breech, Karl Schuler realized that this might crush the nitrocellulose pellets. This observation helped Cooper and the Sandia team focus their search on impact ignition. Their experiments indicated that pellets in the last layer of the powder bags might fracture when rammed into the seated shells, producing burning sparks capable of igniting the adjacent black powder bags. To test this theory, the Navy began full-scale experiments. Just hours before Schwoebel presented Sandia's findings before a nationally televised Senate committee hearing, the Navy's full-scale test produced an explosion similar to Sandia's theory.

The *Iowa* investigation was, Narath declared, "a great example of Sandia's ability to quickly assemble a multidisciplinary engineering and scientific team from many areas and get a job done efficiently." Although they did not prove the cause of the explosion aboard the *Iowa*, Sandia's findings suggested it might have been accidental rather than sabotage. The Navy responded by suspending the firing of sixteen-inch guns on its battleships, reopening its own investigation of the *Iowa* disaster. Subsequently Admiral Kelso, the Chief of Naval Operations, retracted the Navy's earlier accusation that the explosion was a deliberate, intentional act by a member of the crew and acknowledged that it could have been an accident.

The Navy later called on Sandia for other investigations. When mines damaged the USS *Princeton* in the Persian Gulf, for example, the Navy asked for studies useful to the future design of ships. Using computer codes to model structural dynamics, Sandia completed these studies in 1991, the first ever done for an entire ship.

Sandia's support of conventional weapon development by the Army brought it an assignment in 1992 from the Strategic Technologies for the Army in the 21st Century (STAR 21) study managed by the National Research Council. The Army wanted an independent evaluation to determine whether it had overlooked some technology valuable to its future research. "The Army could have asked anybody to review this study, and they chose us, said Max Newsom, "It shows that the Army has some real confidence in us." Having but two months for the review, Newsom marshaled thirty Sandia experts in fields such as propulsion, explosives, and sensors, and also formed a panel including Gerold Yonas, Jim Jacobs, and Andy Lieber. Sandia's final review added a few technologies needing more research to the report and subtracted technologies that were mature, thereby allowing the Army to concentrate its constrained budget on the most promising research initiatives.

TIGER TEAMS

Secretary James D. Watkins, a retired Chief of Naval Operations, took pride in Sandia's work for the Navy as well as in its contributions to the successful conclusion of the Cold War. "The peace through strength concept has carried the day," he asserted during a visit to Sandia. "You should take great pride here in this Laboratory and raise the victory flag because you've done it." Watkins was far less proud, however, of DOE's record in environment, safety, and health programs. Declaring that "the chickens have finally come home to roost," Watkins mandated sweeping reforms to remedy years of inattention, forming an Office of Environmental Management and boosting the budget until DOE had the largest environmental restoration and waste management program in the world. To assure full compliance with environment, safety, and health laws and regulations, Watkins created independent "tiger teams" to audit DOE installations.

Because Sandia designed weapon ordnance, rather than nuclear explosives, it had had little opportunity to accumulate radioactive substances or pollute the environment with them. Yet it operated nuclear reactors and particle accelerators, worked with toxic substances and explosives, and used heavy equipment and high-power machinery. A 1989 DOE report identified nine significant environmental problems at Sandia, including diesel fuel leaks, contaminated landfills, photographic chemical discharges, and a contaminated site at Tonopah Test Range used for plutonium dispersal research in 1963. Sandian Ron Detry predicted in 1989 that environmental cleanup would become a major issue during the 1990s. "In the next decade, we'll see increased attention to problems of the environment," Detry urged, adding that "our improvements must keep pace with the changing expectations of our neighbors and the taxpayers who fund us."

Orval Jones thought many of Sandia's environmental problems arose because its projects rarely ended definitively. Most merely tapered off because no one knew whether funding would return or not. "You may have a cabinet full of chemicals that apply to that project, so you just keep them there," Jones reflected, "then maybe the folks that were working on the project gradually drift off to other jobs; pretty soon nobody even remembers those chemicals."

To assure close attention to these problems, Sandia raised environment, safety, and health (ES&H) programs to the highest administrative levels. Vice president Glen Cheney took charge of ES&H late in 1990, including a directorate already headed by Nestor Ortiz that examined ways in which Sandia could improve the protection provided for its people and their surroundings. Dick Lynch developed a framework for assuring compliance with pertinent laws and Paul Longmire led a team auditing compliance in the weapons area. Joe Stiegler, Bob Park, later joined by Dick Traeger, and hundreds of Sandians spent many hours assessing and correcting various hazards in anticipation of inspections by DOE officials and the tiger teams.

Dick Rohde and Sandians at Livermore prepared corrective actions in response to a surprisingly negative tiger team audit of Sandia's California site in 1990. Apologizing to Watkins, Narath admitted the new standards had proven far more challenging than expected, to which Watkins replied that he had high expectations "not only to ease public anxieties, but also to restore the confidence of the public in DOE's stewardship of the environment."

Forewarned, Sandians in Albuquerque mobilized for the 1991 tiger team visit. From September through December of 1990 a Pre-Tiger Team Self Assessment group, made up of 18 department managers and headed by Ed Graham, evaluated where the Lab stood. To keep Sandians updated on requirements, the Technical Library created a document center providing information to both the staff and the tiger team, and Pace VanDevender proposed the creation of Radio Sandia, a low-powered transmitter on commercial bands to broadcast updates on ES&H, the tiger team,

Part of the Pre-Tiger Team Self Assessment group assembles for a photo in 1990. *Front row from left:* Milo Navratil, Tom Hoban, John Holmes, Dody Hoffman, Bill Burnett, Bob Kelly. *Back row:* John Ledman, Bill Nickell, Gary Mauth, James Kelsey, Gordon Smith, Bob Park, Ken Harper, Rob Wester, Ed Graham.

The Sandia New Mexico Technical Library as it appeared in 1996.

Technical Library

"Getting the right information to the right person at the right time," was the customer service attitude expressed by Sandia California Librarian, Lu Nelson, in 1960. This approach has required Sandia's librarians to focus on the informational needs of the technical staff and has driven the library to continually update both the collection and the technology to manage it.

From a stack of books in the office of manager Sylvan Harris in 1948, the Library has witnessed continual growth, occupying two offices by 1953 and filling a separate building of its own by 1961. By 1992 the collection consisted of 50,000 books, 26,000 periodicals, and 1 million technical reports. Infinite growth is not possible, so the Library has continually weeded the collection and relied on technology to reduce its mass. For example, the Central Technical File, Sandia's collection of information on all technical programs, consisted of 2 million documents by 1971. This room full of paper was reduced to 500 reels of microfilm that are now stored in a few cabinets. Similarly, most of the million technical reports are kept on microfilm or microfiche.

As Library office space expanded, so did advances in indexing and tracking records. In 1956, accountability cards tracked documents from creation to destruction; in 1958, IBM punch cards tracked overdue books; by 1969 the large card catalog was removed and an integrated Livermore-Albuquerque computer system allowed staff in one area to make use of library information from the other. The Library has also taken full advantage of developments in computing to utilize information. In 1977, reference librarians availed themselves of computer-assisted searches, reducing literature search time from several weeks to a matter of days. The Library's on-line book catalog, DOBIS, became operational in 1985 and ten years later the system was updated to Horizon, a client-server graphical user interface integrated library system. Users are now able to access the library catalog from their desks, and alliances with other research and development libraries have expanded that access to a broader range of materials.

The Technical Library remains a dynamic information source to meet Sandia's needs. A consistent customer focus has compelled the Library to adapt in order to serve the constantly changing demands of Sandians. In 1996, Susan Stinchcomb, manager of the Technical Library Research Department, summed up this message of change and service as she looked to the future, "Delivery of electronic information to our customers' desk tops is our strategy."

In 1991, Bruce Hawkinson of Radio Sandia interviews Linda Duffy about the stresses of a tiger team audit.

traffic, and weather. James Baremore got the station up and running. Bruce Hawkinson became Radio Sandia's (KOB20) executive producer when it went on the air in March 1991. The service was discontinued in 1996.

The 1991 tiger team visit, which involved reviews over six weeks by 120 compliance experts, resulted in a reported 342 deficiencies at Sandia New Mexico. Pat Murphy, Jim Wadell, Larry Buxton, Kathy Erickson, Frank Bacon, Yvonne Lassiter, and Donald Duggan, led by Ed Graham, formed the Sandia Tiger Team Action Plan Group to plan actions to rectify the reported deficiencies. The report was completed on time and the corrective action plan it proposed was described by Secretary Watkins as "a fine example of the technical and managerial excellence that we expect of our National Laboratories."

According to Narath, the tiger team audits indicated that Sandia and other national laboratories had not been properly sensitive to the environment in which DOE operated — political, economic, and social. Joe Stiegler admitted that Sandians experienced frustration as they sought to comply "with laws that are very complex." The increased emphasis and funding for environmental restoration at DOE facilities, however, presented new opportunities for Sandia's research and development teams.

A DOE report estimated the environmental cleanup bill for its facilities at a stunning $230 billion. Because Sandia was one of the least contaminated sites in the complex, it required a small fraction of the total; yet it became involved immediately in the remedial program because the Secretary of Energy urged its participation in "smart cleanup," meaning research to identify means of reducing the cleanup costs. "For the first time in the history of the agency, this area of research is being recognized at top levels as significant and important," said Bill Luth, who led Sandia's environmental technology team. Luth and Dick Lynch urged researchers throughout Sandia to consider the development of environmentally friendly technologies.

According to Luth, the Sandia approach to dealing with hazardous materials rested on an understanding that it was necessary not only to treat toxic and hazardous waste, but also to minimize its production. Some simple techniques involved recycling: instead of incinerating used oil from its machines, Sandia sent it to a refinery for reuse; instead of incinerating old fluorescent lamps, it sent them to a plant for recycling. Its efforts at waste minimization were applicable throughout the DOE complex and, by extension, to private industry.

Recycling interested Sandians, and they contributed to the technology through development of an automated system for sorting various kinds of plastics. Using an

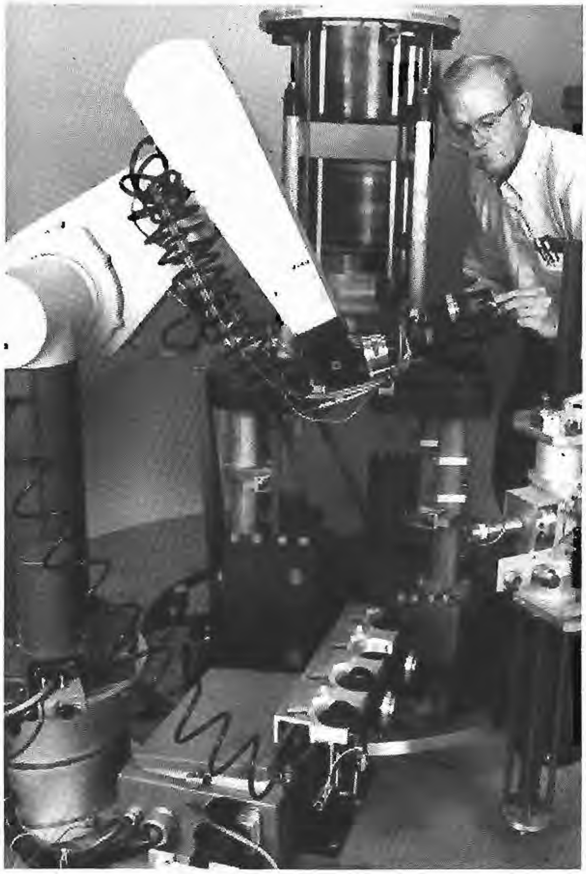
Suzanne Stanton demonstrates equipment Sandia developed to automatically sort plastics for recycling.

artificial neural network able to discern patterns, Suzanne Stanton, Greg Hebner, and Kathy Alam developed a means of identifying different plastics by the spectrum of light they absorbed and then sorting them as they moved along conveyor belts. "History shows that people don't want to sort their trash," observed Hebner, pointing out that "by reducing the costs of in-plant plastics sorting, maybe this system will ultimately make plastic recycling more attractive and boost the volume of plastic that is recycled."

With DOE funding, Sandia also initiated environmentally conscious manufacturing research led by Mike Cieslak and Joan Woodard, which focused on reducing the use of toxic solvents. Sandians developed substitutes for industrial solvents used to remove machine oils, fingerprints and contaminants from printed circuit boards and pursued new cleaning methods such as laser ablation, plasma cleaning, and new soldering techniques for manufacturing. These improvements applied to both Sandia's traditional weapon mission as well as new ventures into the world of industry.

Sandia's solar thermal research proved useful for toxic waste management. Craig Tyner coordinated two efforts to use solar energy to chemically change toxic wastes into harmless byproducts. One used a catalyst and ultraviolet light to convert organic solvents and pesticides into water, carbon dioxide, and dilute acids. Developed in cooperation with the National Renewable Energy Laboratory in 1992, this solar detoxification system passed field tests of its ability to destroy organic toxins in groundwater. "These methods are important to DOE because if we can change the state of hazardous waste to make it

Larry Yellowhorse in 1992 adjusts a solar-powered detoxification system developed to heat and destroy organic toxins in groundwater.



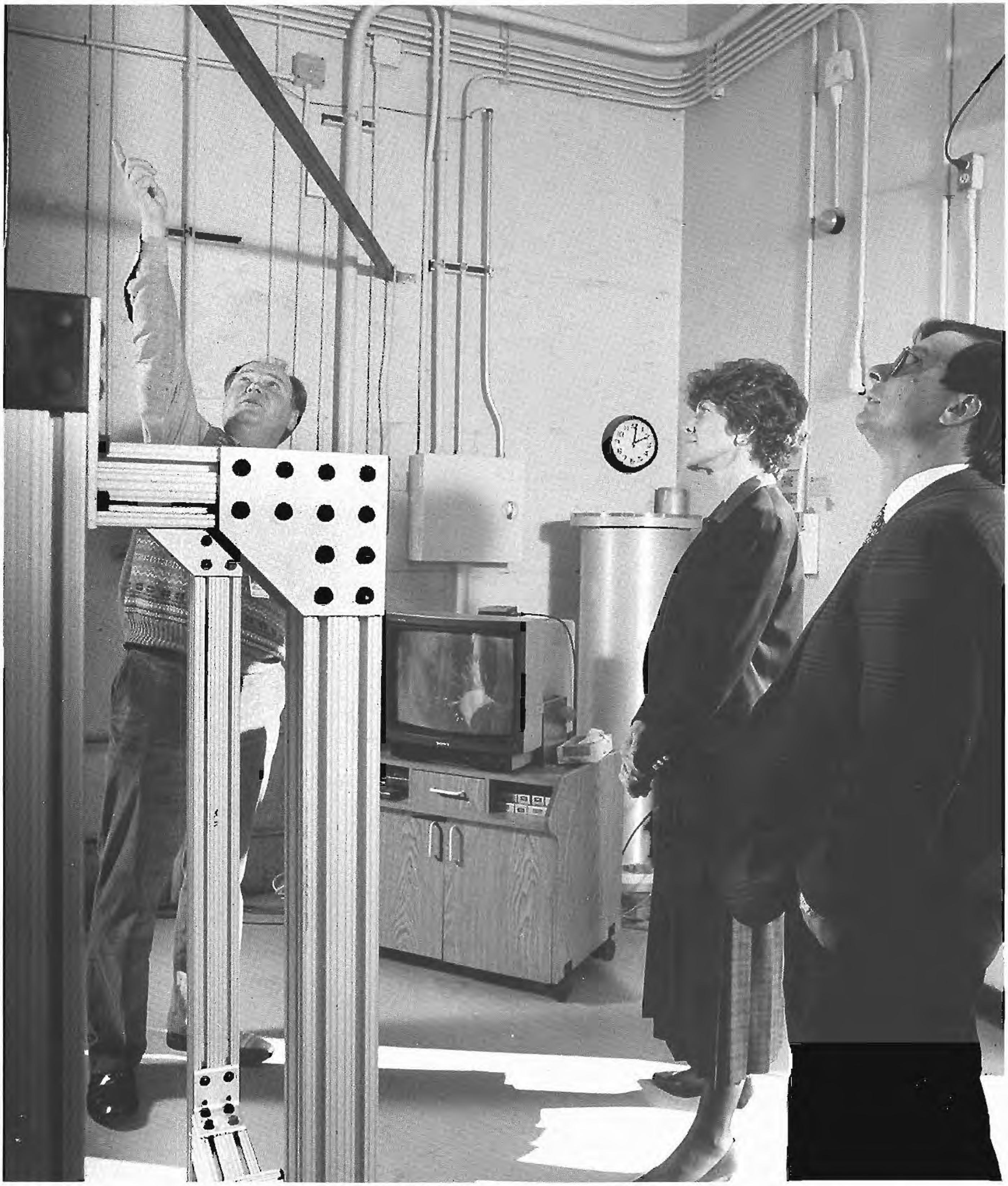
Siegfried Thunborg adjusts a remote maintenance robot that Sandia developed for nuclear reactor repairs.

non-toxic," said Tyner, "we have the disposal problem whipped."

A second method used high temperatures to convert toxic substances into fuels or chemical feedstocks. Sheridan Johnston and Steve Rice at Livermore used a supercritical water oxidation process, developed at MIT, to heat water under high pressure and oxidize the waste into harmless byproducts in the water. Because this method could destroy chemical obscurants, dyes, and pyrotechnics within seconds, the military services and Defense agencies funded engineering for a pilot-scale supercritical reactor that might eventually provide an alternative to incineration for the disposal of these materials.

In the "swords into plowshares" tradition, Jack Swearengen led a team studying innovative disposal of explosives and rocket propellants left over from Cold War weapons research and testing. One method involved cryocycling — freezing rocket propellants with liquid nitrogen and fracturing them into pellets that might be converted to mining explosives or burned with coal to generate electricity. Sandia also offered surplus gunpowder to a small business considering converting it into agricultural fertilizer or animal feed supplements.

Group portrait of various robotic vehicles developed at Sandia for service in environments hazardous to people such as battlefields, toxic waste sites, or even on the moon.



Linn Derickson points out features of the steam reforming evaporator improved for toxic waste cleanup to Joan Woodard and Larry Bustard.

Sandia's robotic all-terrain lunar exploration rover (RATLER) can cross obstacles as large as its wheel diameter. It might be used to explore the moon.

By designing robots and intelligent systems for remote operations in radiation environments, Sandia also assisted in DOE's efforts to reduce human exposure to radioactive wastes at remediation and restoration sites. Using lasers, ultrasonic sensors, and sophisticated three-dimensional viewing, Sandia developed remote control systems in which the operators had a sense of being in the environment and feeling the robot's motions. Joining with other DOE laboratories, Sandia applied its robotic technologies toward development of large manipulators to clean wastes in underground storage tanks such as those at Hanford, Washington. These and related technologies also went into Sandia's designs for mobile robots to locate and retrieve buried wastes and for a system to automate weapon disassembly at Pantex during the massive nuclear weapons dismantlement program of the 1990s. "This new generation of robots has tremendous potential," predicted Pat Eicker, director of Sandia's intelligent robotics center. "These machines will have the ability to program themselves to do different tasks, react autonomously to unexpected conditions, and eliminate the need to risk human lives in dangerous environments."

Because environmental restoration technologies offered international benefits, Tom Hunter announced that Sandia hoped to contribute to global solutions. Charlene Harlan and Mark Harrington, for instance, developed for DOE an electronic data base called EnviroTRADE for international exchange of information useful to environmental restoration. In 1993, this information system was made available to Russia and provided information on Russian sites to the United States.

"We're not offering any miracles," Narath said, summing up Sandia's advance to the forefront of DOE's smart cleanup, "but we can make some significant contributions."

DESERT STORM

The interlude following the collapse of the Berlin Wall and the disintegration of communist government in Eastern Europe ended abruptly in late 1990. "We went from positive euphoria to being in a war," said Orval Jones as U.S. armed forces went to the Middle East for Operations Desert Shield and Desert Storm.

Following Iraq's invasion of Kuwait in August 1990 and the United Nations response with Operation Desert Shield, Sandia quickly offered its technological expertise to the armed forces. Meeting with the Defense Science Board, Bob Clem of exploratory programs learned that Sandia could contribute

A three-dimensional image generated by Sandia's SAR system of a mesa near Albuquerque. In addition to defense and verification applications, this technology may prove useful for tracking oil spills and monitoring agricultural crops.

immediately through rushed improvements in the technological capability to identify armored vehicles from the air. This ability to "see" through clouds or darkness with the advanced radar systems developed in the late 1980s proved useful for targeting and battlefield assessment. "Most of the effective fighting and intelligence gathering during Desert Storm was done at night," Bob Huelskamp of Sandia commented later. "If you have synthetic aperture radar (SAR) and the enemy doesn't, you can see him and he can't see you." Narath pointed out that Sandia's achievements in massively parallel computing made it possible to solve pattern recognition problems involving SAR in a timely manner. "These calculations, performed only at Sandia, were so complex that they could not have been accomplished in time for military use by any other means," he declared.

As the Desert Shield forces mobilized, Iraqi forces prepared elaborate defensive positions along the Kuwait/Saudi border, including oil-filled trenches backed by minefields and concertina wire and by infantry positions supported by armor and artillery. Conducting training exercises against such defenses, the U.S. Army Corps of Engineers predicted high casualty rates for the attacking forces. To help counter this threat, Sandia developed a large fuel-air explosive, similar in concept to the Pave Pat developed a quarter century earlier, but delivered on a remote-controlled robotic vehicle. A single weapon could neutralize blast-sensitive mines and dug-in troops over a one-acre area. A team led by Mike Hightower designed, built, and tested this liquid propane device in less than a month.

Facing the possibility of conducting amphibious assaults on the heavily mined beaches of Kuwait, the Marine Corps requested assistance in defining ways to clear the beaches of shallow-water mines ahead of troop landings. At Sandia, Steve Roehrig's robotic vehicle team developed remote controls for landing craft that could neutralize paths through mines to the beaches. Thirty-one days after they started the design, they demonstrated the control system for the Marine Corps in San Diego Bay using military landing craft.

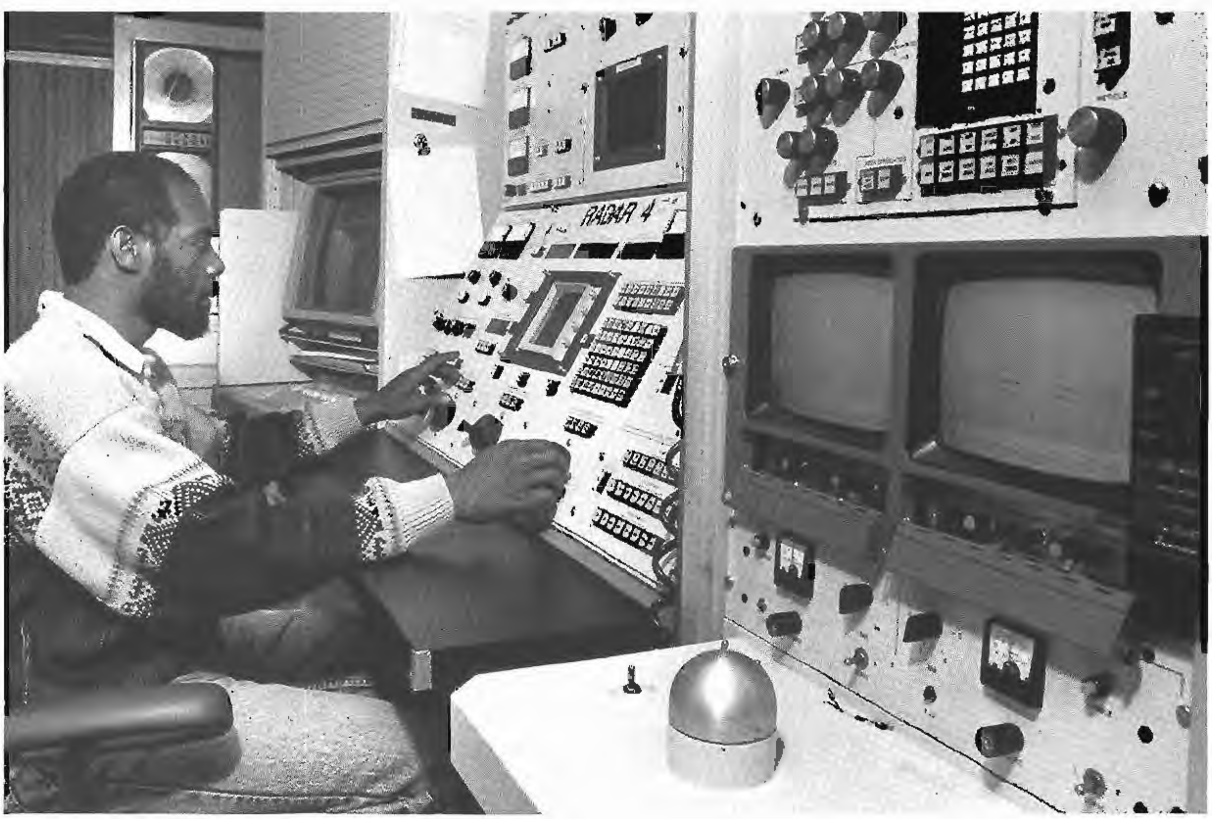
The Defense Advanced Research Projects Agency requested that laboratories and industry participate in a "science fair" for field evaluation of competing ideas for distinguishing between friends and foes. With just ten days to work, Max Newsom assembled a multidisciplinary team from many parts of Sandia to brainstorm possible near-term solutions. Sandia's solution involved turning the infrared emissions of a tank's engine into a distinctive signal by installing louvers that opened and closed like venetian blinds in a frame mounted over the tank's engine. Pilots with night-vision equipment could see the flash as the louvers hid and revealed the heat source. With support from Sandia's development shops, Ray Klein and the team designed, built, and fielded this system in a week. "It was great to see that Sandia can still respond to these kinds of problems on a crash basis," said Newsom, comparing the response with similar experiences during the Vietnam war.

A related assignment came when it was learned that the Iraqis had planted explosives on oil wellheads in Kuwait. From Sandia's energy and environment programs, Dennis Engi and Virgil Dugan recruited oil reservoir experts Dave Northrop, John Waggoner, and Norm Warpinski; combustion experts Tom Fletcher and Ken Marx; and atmospheric specialists Bernie Zak, Hugh Church, and

Some of Sandia's team formed in 1990 to study Iraqi use of oil as a weapon. *Standing from left:* Norm Warpinski, John Waggoner, Wayne Einfeld, Sharon Walker. *Seated,* Bernie Zak and Mike Edenburn.

During Desert Storm, Sandia developed remote controls for landing craft to clear mines and beach barriers, testing them aboard this Navy landing craft in San Diego Bay.

Parris Holmes operates radar at Sandia's Tonopah Test Range, which hosted vital military device testing during Operation Desert Shield in 1990.



Virgil Dugan and Dennis Engi in 1991 discuss Sandia's report on burning oil well effects in Kuwait.

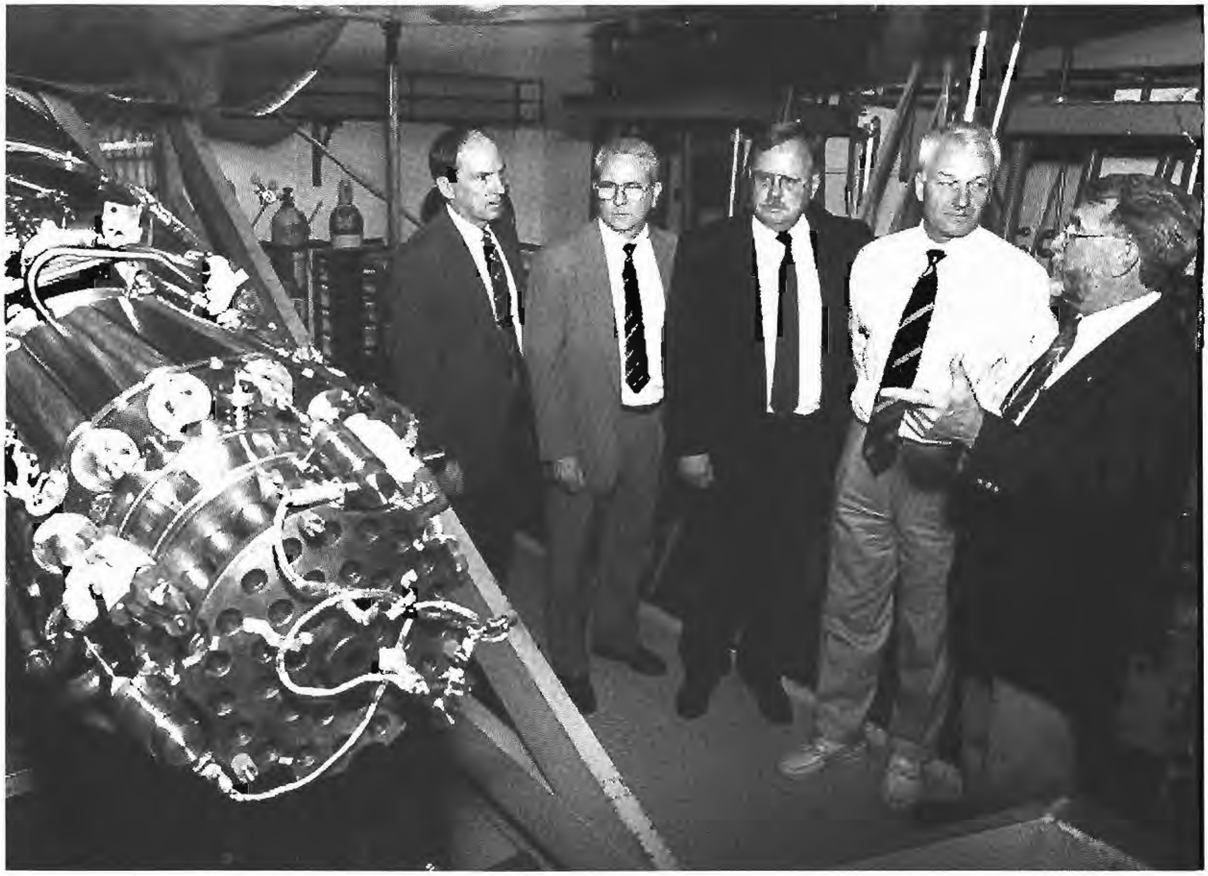
Wayne Einfeld. They predicted the effects of detonations at the wellheads — smoke plumes obscuring optical targeting, damage to water supplies and the environment, and loss of millions of barrels of oil. After many oil wells were destroyed and set on fire by Iraq, Sandia advised the military and commercial fire fighters on potential methods to control and cap the hundreds of wild oil wells. Dugan and Engi briefed Secretary Watkins along with White House and Pentagon staff members, then went to Saudi Arabia to report Sandia's predictions to field commanders. Dugan concluded, "Maybe the most direct military value of our work was in providing the military with indications of the kind of environment that they might have to fight in. In fact, I have been told that some operational strategies were changed as a result."

After successful completion of Operation Desert Storm, United Nations Resolution 687 prohibited Iraq from acquiring weapons of mass destruction and the missiles to deliver them, and the UN sent inspection teams into Iraq to enforce this mandate. Four Sandians took part in these inspection programs. John Taylor coordinated activities for DOE at the State department, and Paul Stokes advised the UN Special Commission in New York. Later, in 1994, Stokes began a two-year assignment in Vienna as Deputy Leader for Analysis of the International Atomic Energy Agency Action Team on Iraq. Paul Cooper and Charlie Burks joined UN teams working in Iraq, and Burks was a member of the UN inspection team held hostage in a Baghdad parking lot in September 1991. Inspectors were amazed at what they found. It was reported, for example, that Iraq, using a uranium enrichment technology that the United States had abandoned in 1945, had come closer than anyone had previously suspected to developing a nuclear weapon.

Reflecting on lessons of the Persian Gulf war, Orval Jones predicted a heightened focus on low-cost, readily testable, and smart weapons capable of precise and penetrating strikes against hardened targets. "Our work with China Lake Naval Laboratory on the advanced bomb family may be particularly important," he said. The lesson that smart conventional weapons could win battles and wars with minimum casualties was not lost on defense planners who envisaged a reduced role for nuclear weapons in future military strategy.

"The technology base that made high-tech weapons so effective in the Gulf War must remain robust and vital if it is to serve national security in the future," said Narath in 1991, announcing Sandia's alliance with Los Alamos, the Air Force's Phillips Laboratory, and the University of New Mexico, to make New Mexico an aerospace research center. Frank Thome, Lou Cropp, and Dennis Berry had worked several years to create this institutional alliance. Its first announced project, sponsored by SDIO and later the Defense Nuclear Agency, was a study of the Russian Topaz II space nuclear power system. Based at the University of New Mexico, the Topaz studies were related to the space propulsion program managed at Sandia by Bill Snyder and Jack Walker. Snyder's team examined ways Sandia's technology could apply to space travel. It studied lasers as potential power sources for spacecraft and investigated the use of nuclear rockets to shorten the time required for space travel. Noting that conventional rockets would require up to three years to transport astronauts to Mars and back, while a nuclear rocket might complete it in a year, Snyder said, "The way I look at it, I'm not sure that a human can live in a spacecraft the size of a Volkswagen for 2.5 to 3 years."

While the United States had chosen thermoelectric systems for auxiliary power in



Inspection of a Russian Topaz space power reactor brought to New Mexico for study in 1992. *Left to right:* Dan Hartley, Russian researcher Valerie Sinkevich, Sam Blankenship of Georgia Tech, Richard Truly of NASA and Georgia Tech, Topaz program manager Frank Thome.

spacecraft, the Soviets had used the thermionic Topaz II system, which had no moving parts. When SDIO funded the purchase from Russia of Topaz reactors for study by the New Mexico alliance, Sandia took lead responsibility for assessing their safety and designing a reentry heat shield, and built a facility to perform electrical tests on the thermionic system. Dan Hartley predicted that spinoffs from thermionic technology might include new high-temperature alloys and insulators.

COMPETITIVE ENERGY

The Bush administration supported increased energy research funding, especially for clean coal research. In addition, funding for renewable energy — wind, solar, biomass, and geothermal — nearly doubled during the Bush years, and energy conservation programs received additional support. With this added funding, Sandia continued its efforts to develop renewable energy sources competitive in cost with conventional fossil fuel sources.

The Solar One central receiver experiment near Barstow, California, operated from 1982 to 1988. In 1991, Greg Kolb, Jim Chavez, and Dan Alpert of Sandia initiated a campaign to convince utility companies to retrofit Solar One with a new molten salt receiver. Molten salt, similar to the nitrate salt in fertilizer, can store heat more efficiently than water, making steam after sunset and on cloudy days. Sandia had tested three salt receivers and a salt thermal storage system at its power tower. A nine-company consortium was formed to develop Solar Two with DOE as a funding partner. While development costs exceeded those for comparable fossil fuel plants, the sunlight fuel was free. "It's like buying a new car with 30 years worth of fuel already in it," Kolb explained.

Sandia reviewed Solar Two's design and construction and helped resolve technical issues. After installing the new receiver, new and larger heliostats, a thermal storage tank system, and a salt-to-steam generator, the consortium will share the ten-megawatts of electricity Solar Two will produce when completed late in the century. "Solar Two is the first step toward commercializing solar central receiver technology," Kolb said, describing it as the next phase leading toward development of a 200-megawatt commercial solar plant during the 21st century.

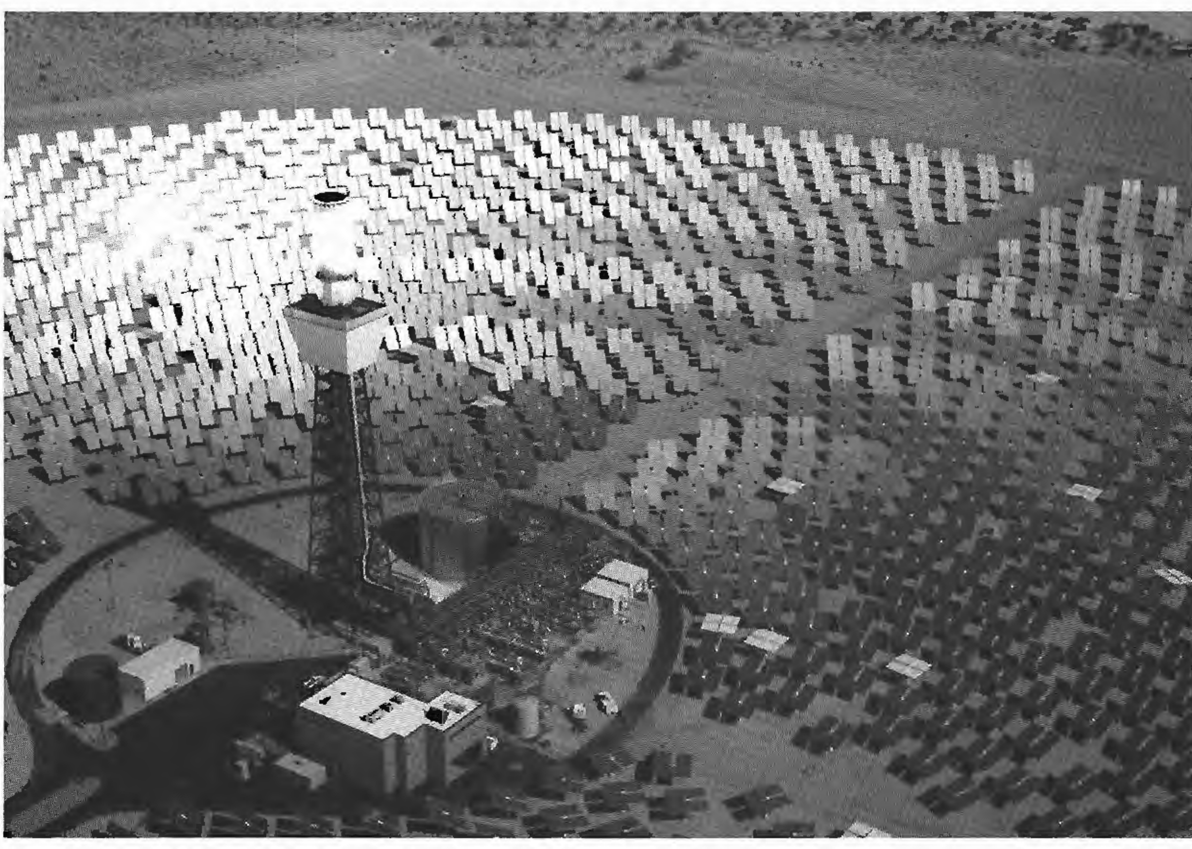
Although on a different scale than Solar Two, power storage concerned Sandia's battery research specialists as well. Their well-known expertise in battery development for nuclear weapons attracted utility companies and commercial battery and automobile manufacturers to Sandia during the 1990s. In cooperation with the U.S. Advanced Battery Consortium and other partners, Sandia studied lithium-ion and sodium-sulfur rechargeable batteries for portable electronics, lithium-polymer batteries for electric cars, and nickel-hydrogen batteries for spacecraft. Many Sandia battery innovations, notably TA23 glass and sodium-sulfur technology, were soon commercialized, but major technological challenges remained. Sam Levy of Sandia's battery group identified these as corrosion of battery canning and sealing materials, along with environmentally conscious manufacturing and disposal of batteries. "Once these are corrected," Levy predicted, "the electrochemical systems will operate with a higher degree of reliability."

Sam Levy of Sandia's battery technology group in 1991 inspects a mock battery made of transparent plastic.

Nick Magnani represented Sandia at the White House in 1991 when President Bush approved DOE's collaboration with the Advanced Battery Consortium to improve batteries for electric cars mandated by law in some states. As early as the 1960s, Sandians such as Paul Stickler had converted small cars to battery power for personal use, and Dick Bassett headed electric car studies at Sandia during the 1970s. While these early efforts had aimed primarily at increased transportation economy, during the 1990s DOE and industry renewed their interest in electric cars as one route to reducing the emissions that cause smog.

Competition for developing vehicles without emissions included Sandia's research into the use of hydrogen fuel by Jay Keller, George Thomas, Walter Bauer, and associates at the Combustion Research Facility. With its partner laboratories and universities, Sandia envisioned a hybrid engine, using a hydrogen-fueled engine to drive a generator to power electric motors turning the car's wheels. Researchers had a small hydrogen engine in operation by 1995 and planned to scale it up. They also planned to investigate reducing the size of hydrogen fuel cells of the type used for power aboard space shuttles in order to use them in vehicles. Photovoltaics, systems that convert sunlight directly into electric power, had become an increasingly competitive energy source by the 1990s. In 1988, in cooperation with Stanford University and the Varian Company, Sandia used stacked, multi-junction semiconductors to produce a photovoltaic cell with a record thirty-one percent efficiency in converting solar to

The experimental vertical-axis wind turbine built at Bushland, Texas, using a 1980 Sandia design pointed the way toward future utilization of wind energy.



Experiments with Solar One in California led in the 1990s to the stepped-up power of Solar Two.

Left: Clement Chiang and Elizabeth Richards admire Sandia's experimental photovoltaic module that in 1989 set a world record for efficient conversion of solar into electrical energy.

Below right: Tom Mancini in 1994 inspects a Stirling heat engine to be coupled to the solar concentrator behind him for modular solar power applications.

Vietnamese villagers hoist a photovoltaic panel into place as part of a program designed to bring electricity to the Vietnamese countryside.

electric power; the search for forty percent efficiency continued. Sandia helped expand markets for commercial photovoltaic power in Honduras, Guatemala, Mexico, and other nations with abundant sunlight that could be harnessed to pump water, provide refrigeration, and power communications. In 1992, following Hurricane Andrew, Sandia helped provide photovoltaic power at relief shelters in Florida to serve during commercial power outages, and continued furnishing this service during subsequent natural disasters, notably after 1995's Hurricane Marilyn in the Virgin Islands. And in 1995, Sandia joined with the nonprofit Solar Electric Light Fund to install solar photovoltaic systems at rural villages in Vietnam.

Not so well known as photovoltaics, dish-Stirling technology had been under development since the 1970s. Sandia worked with Solar Kinetics, Inc., during the 1980s to replace heavy glass heliostats (mirrors) with lightweight stretched membranes coated with shiny polymer as the reflective surface. Less expensive than glass, stretched-membrane dishes could concentrate solar energy at their focal point to intensities a thousand times that of normal sunlight. Inside the receiver, heat from the sunlight vaporized sodium metal, which heated helium gas inside the Stirling heat engine. Alternately heating and cooling helium in the engine drove a piston connected to an alternator to make electricity.

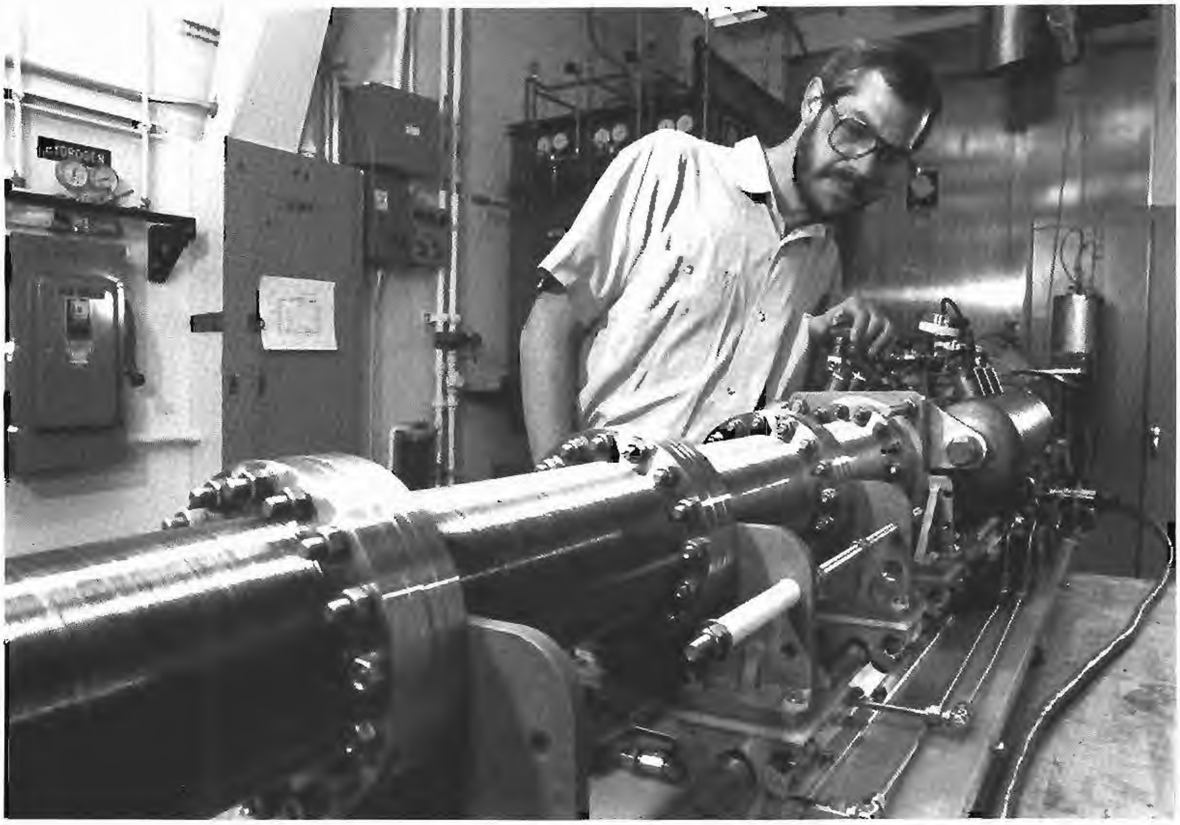
Rich Diver and Tom Mancini worked with Cummins Power Generation, Science Applications, and other firms to commercialize dish-Stirling technology during the 1990s. Able to produce electricity at lower rates per kilowatt-hour than diesel-generated electricity and to be placed where the power was needed, with no power transmission lines required, this versatile system could also be operated by heating the engine with natural gas or oil when clouds blocked the sunlight. Sandia had high hopes for this system's future, especially as stand-alone power sources in equatorial rural regions. "If you lived far away from a power grid," explained Diver, "it would probably be a lot cheaper to install something like this than to pay for running an electric line to your property."

COMPETITIVE FUSION

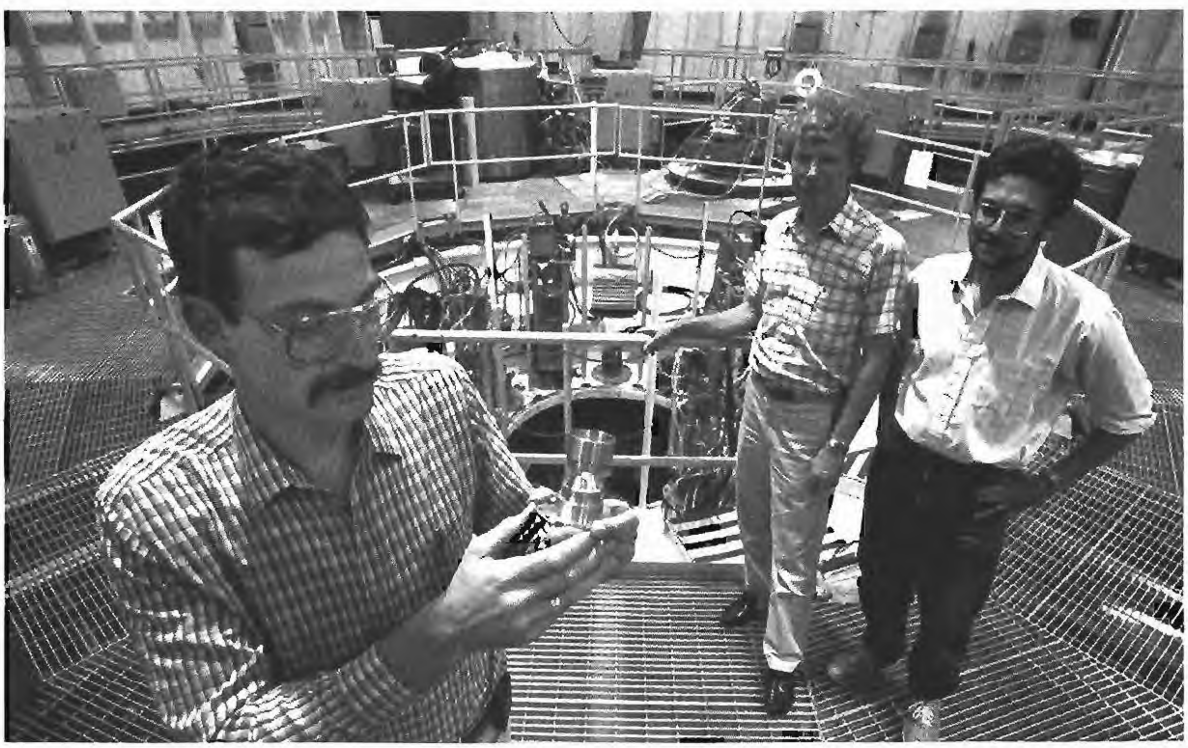
"Thermonuclear fusion is surely the Grail of all energy research programs in the world," said Don Cook, declaring that success could make fossil fuel energy as obsolete as tallow candles. Although the search for fusion energy involved scientific cooperation on a global scale, it also was marked by intense competition, especially during the constrained budgeting of the 1990s. Sandia's ion beam approach to inertial confinement fusion (ICF) competed primarily with laser beam fusion research at Lawrence Livermore National Laboratory.

The Particle Beam Fusion Accelerator II (PBFA II) achieved a record power level of five terawatts (five trillion watts) of power per square centimeter of target in 1989. Experiments continued on this machine during the 1990s, passing several critical reviews by panels from DOE and the National Academy of Sciences. In 1996 a record-breaking output of 85 terawatts was achieved — more than 50 times the output of the U.S. utility grid. A 1995 review approved upgrading PBFA II for continued experimentation, in order to contribute to the 21st century design of a Laboratory Microfusion Facility useful for both aboveground weapon effects testing and fusion research.

Sandia contributed to both inertial and magnetic fusion studies. For the magnetic fusion machines, called tokamaks, Sandia investigated the interaction of fusion plasma with the "first wall" materials, and designed and fabricated components able to function in harsh fusion plasmas. Under the management of Wil Gauster, Sandians performed diagnostics, tritium assessments, and materials studies for the Princeton Tokamak Fusion Test Reactor and for experimental tokamaks in Germany, France, and Japan. When the United States, Japan, Russia, and the European Community agreed in 1992 to joint design of the International Thermonuclear Experimental Reactor (ITER), Sandia undertook research that was incorporated into the design of several reactor components. Ongoing ITER research is conducted at sites in Germany, Japan, and the United States, with the four participants each supplying about 50 scientists. As part of this



Jonathan Watkins in 1990 checks a fast-scanning probe designed at Sandia to measure plasma density, electron temperature, and floating potential inside magnetic confinement tokamaks used for fusion research.



Gordon Chandler, holding a target chamber, Paul Rockett, and Mark Derzon stand atop Sandia's Particle Beam Fusion Accelerator II in 1993. The accelerator and target chamber were used in inertial confinement fusion experiments.

effort, Gauster left in early 1993 for a three-year assignment as Deputy Head of the Garching Joint Work Site of the ITER project in Garching, Germany, where the work on the in-vessel components is done.

Magnetic confinement fusion received a boost in 1994 when the tokamak at Princeton Laboratory generated 10.7 megawatts of fusion power, a promising milestone in the drive toward the break-even point. Advocates of inertial confinement fusion, however, still claimed Sandia was forging the cheapest and most direct path toward achieving fusion energy production.

During the 1990s, Sandia in cooperation with Cornell University developed repetitive high-energy pulsed power (RHEPP) accelerators that provided a broad, rather than focused beam of particles. These robust accelerators could be used by industry to kill bacteria in meat, harden steel, or make water safe to drink. RHEPP drew media attention because it offered a way of killing the *E. coli* bacteria that was contaminating mass-processed meat and had caused fatalities among consumers. The metals industry, meanwhile, took an interest in the use of RHEPP to melt the surfaces of metals, hardening them against wear and corrosion and obviating the need for using hazardous metal-plating chemicals.

COMPETITIVE TECHNOLOGY

"While the Cold War was an economic victory — the other side saw that it could not afford to continue — the economic contest is actually intensifying," Al Narath observed. "It has political and social dimensions, certainly, but the technological dimension is central. To be competitive, our nation must keep pace technologically. And that's where we fit in."

As noted earlier, Sandia's ventures into technology transfer began on a small scale during the 1960s and intensified during the 1980s with strong support from industry and Congress. The rationale was perhaps phrased best by Robert Noyce, a founder of Intel Corporation. "The economic threat to America is greater than the threat posed by Soviet missiles," he declared, "so we must change the focus of research to address the economic threat." Following this reasoning and concerned by growing trade deficits, Congress encouraged national laboratories to use their technologies to help shore up faltering industries deemed vital to economic defense, and in 1989 Senators Domenici and Bingaman sponsored the bipartisan National Competitiveness Technology Transfer Act. It approved technology transfer as a program with national significance and provided guidelines for Sandia and other laboratories to enter into partnerships known as cooperative research and development agreements (CRADAs) with industries and universities.

Technology transfer is a contact sport. Conducting it successfully meant moving more often from behind Sandia's fence to mingle with industrial and university managers, and to attend professional and trade association conferences. In brief, Sandians had to market their abilities, a novel experience for managers not involved in the energy and work-for-others programs. Narath pointed to Sandia's energy programs as models for how technology transfer should be done. Solar thermal, photovoltaics, drilling, and oil recovery programs had invited industrial participation from the beginning, and in some cases actually fostered new industries and jobs. Although this might require a cultural change, Narath thought it well worth the effort. "AT&T had to go to Japan to buy products based on a number of Bell Labs inventions — that's embarrassing," he lamented.

After Narath and Bruce Twining of DOE's Albuquerque office signed an agreement in January 1991 formally recognizing technology transfer as a Sandia responsibility and defining procedures, Sandia embarked on major efforts to enter into research partnerships with industries large and small. Sandia's microelectronics center inked the first CRADA with Signetics of Albuquerque, for reliability testing and failure analysis. Clint Anderson of Signetics commented, "Sandia's testing capabilities are not exceeded anywhere in the world."

Those capabilities were applied in another CRADA when Sandia helped Interstate Glass

Distributors (IGD), a small Albuquerque auto glass distributing company, to develop the "crate" — a lightweight, stackable, collapsible, reusable, recyclable container made of recycled plastic, meant to hold some thirty egg-fragile automobile windshields during cross-country shipping. Breakage of auto glass during shipping amounts to $15 million annually. IGD president Dago Ruiz had drawn up plans for the crate in early 1993, built a prototype, and subjected it to rigorous testing by loading it onto a pickup truck and going "four-wheeling" on Albuquerque's West Mesa. But significant design improvements could only be made with hard, quantified data about the crate's ability to withstand realistic shipping conditions. Eventually, IGD approached Sandia and an eight-month CRADA was arranged. Sandia's contribution was proffered through the technical assistance of Dave Harding of the Transportation Technology Department who quantified design constraints and performed stress analyses on the IGD crate. In the end, Sandia recommended optimal configurations and sizes for certain high-stress structural elements, such as hinges and joints, that led to a sturdier final design. IGD applied for a patent in 1995. "Without Sandia's technical expertise and the credibility it has given us in dealing with manufacturers, I'm not sure we could have proceeded with this process," said Ruiz. "It was surprisingly easy to work with Sandia."

In 1991, CRADA competition among DOE multiprogram laboratories became fierce. Within a year, however, Sandia had entered into 100 CRADAs, and the total soon exceeded 200, more than any of the other DOE multiprogram laboratories, signaling success for Sandia's technology transfer initiatives. Recounting the truism that science is the pursuit of truth and engineering is the pursuit of results, Lee Bray observed that nationally the pendulum had swung in the direction of results, "People want to see evidence of payback."

In addition to CRADAs, Sandia's technology transfer program embraced personnel exchanges, patent licensing, user facilities, cost-shared contracts, technical assistance, and simple information distribution. Sandia provided direct technical advice and assistance for hundreds of small businesses that could not afford or await CRADAs. One case in 1992 that got media attention involved an Albuquerque business making paper sacks for fast-food restaurants. When the sacks came apart at the seams and customers lost their lunches, the firm's owner requested Sandia's assistance. Sandia sent Pete Stromberg to look at the local paper-bag production line. He learned the company had recently begun using recycled paper in the bags, and this paper absorbed the glue applied to hold the seams together. At his recommendation, the company installed glue sensors and a logic controller on the production line to measure glue application. "I think this project is a good example of what Sandia can do to help small businesses," Stromberg said afterwards.

After honing its technology transfer initiative by maximizing small CRADAs with individual companies, Sandia focused on teamwork with clusters of companies in consortia and alliances that joined laboratories, industry, and universities in broad, industry-driven and pre-competitive research and development. Partners joining in these larger CRADAs shared both the costs and benefits alike, eliminating the difficulty of selecting partners from among several competitors.

Sandia's partnership with the SEMATECH consortium on enhancing microelectronics fabrication, improving microelectronics quality, and developing environmentally conscious production methods for integrated circuits blossomed during the 1990s. It included more than thirty projects aimed at keeping the U.S. semiconductor industry at the forefront of global competition. SEMATECH president Bill Spencer, a former Sandian, asserted that the computer modeling expertise developed by Sandia in its nuclear weapon programs proved highly useful in reducing semiconductor research time and costs.

Metallurgist Frank Zanner fostered the formation of the Specialty Metals Processing Consortium in 1990. The consortium consisted of a dozen small companies and supported research on high-strength metals used in jet engines, high-speed drills, nuclear reactors, and applications critical to defense. "The approach that made the most sense economically was for them to support research together and to share

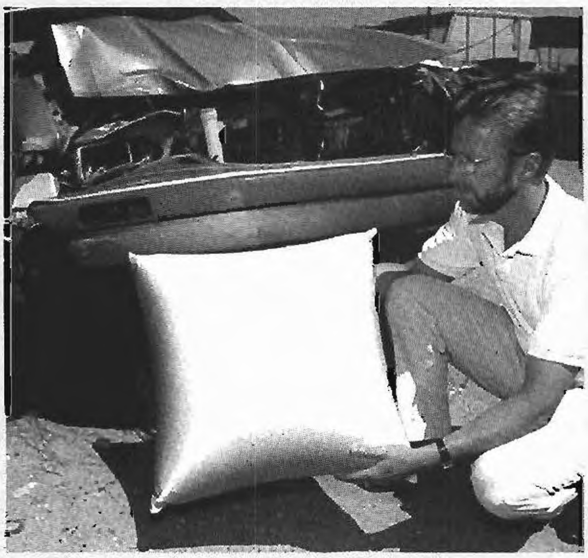
Rod Geer, manager of Media Relations, observes as Secretary of Energy Hazel O'Leary responds to reporters' questions during an April 1993 tour of Sandia. Left to right: O'Leary, Geer, Peter Herrera (Associated Press), Karen McDaniel (KOAT-TV), Larry Spohn (Albuquerque Tribune), and an unidentified reporter from 770 KOB.

Media and Public Relations

When Sandia separated from Los Alamos in 1949, it was obvious that the Laboratory would need a coordinated public relations program. From the very beginning, Sandia's Public Relations Department took responsibility for developing and maintaining relationships with local and national media; arranging and hosting media visits, interviews, and filming; providing public relations counsel to staff members and management; writing news releases on Sandia accomplishments; and responding to media inquiries regarding Sandia.

In the early years, Public Relations was a driving force in the founding of the Coronado Club; produced the first publicly released film on Sandia, *The Sandia Story*; formed the Employee Contribution Plan; initiated the first Family Day in 1959; and established the Employee Service Recognition Program in the late 1950s. In 1961, Sandia was emerging from the cloak of secrecy surrounding the early days of atomic weaponry and although the Labs was little known nationally, significant technologies were developed of interest to the private sector. Jim Mitchell of Public Relations was asked by Ted Sherwin of the Public Information Division to begin an expanded effort to disseminate information on Sandia science to the national media. The first significant piece of Sandia technology to strike the fancy of the national press was the laminar air flow clean room. The story was carried in a *Time* article in April 1962 and resulted in about 1000 inquiries to Public Relations. Other highly publicized technologies that have received heavy media attention over the years include: rolamite (1967), the insulin pump (1979), and the micromachine (1994).

Providing information to the media about Sandia's accomplishments has proven crucial to the Labs' business. Occasionally, large media events such as Secretary of Energy Hazel O'Leary's visit in 1993 required extensive arrangements with various agencies. However, the routine preparations necessary for media campaigns, such as that for a 1995 airbag technology, were the primary responsibility of the Media Relations Department.



Sandia researcher Kenneth Gwinn displays an inflated Precision Technology Airbag in front of an accident-damaged car.

In March 1995, planning began for a public relations campaign to announce and publicize a revolutionary airbag technology developed through collaboration between Sandia and Precision Fabrics Group (PFG), Inc. of Greensboro, North Carolina. The airbag was the first fully redesigned airbag offering significant improvements in the last 25 years and promised to result in safer automobiles and greater interior design flexibility for automakers. Planning for the air bag announcement included library research, development of a key message for the campaign, and logistical planning for a press conference to be held in Washington, DC at the National Press Club. A joint Sandia and PFG news release was written, a video news release completed, and photographs and other display materials developed. The pervasive message woven into the campaign was that the airbag was the result of a public and private partnership based on the leveraging of technologies originally developed for nuclear weapon applications.

A press conference was held in June 1995 on the day that C. Paul Robinson, Sandia president, was scheduled to testify before a Congressional subcommittee on technology transfer. Numerous key media attended the press conference including CNN and CBS. The news release was distributed by mail, e-mail, and PR Newswire and posted on two electronic bulletin boards for journalists. Media coverage of the technology was heavy: media analysis conducted in December 1995 showed the total estimated reach of the airbag media campaign in terms of circulation and broadcast audience size was about 69 million. The airbag was chosen for inclusion in *Popular Science's* "Best of What's New" issue in December 1995 and was nominated for a *Discover* Magazine Technology Award. This media event depicts the importance of Sandia's Media and Public Relations Department in dissemination of a key technology to the media and public.

Welding has been critical to both weapon design and industry. Using computers, Sandians like this technician seek better understanding of welding processes.

the results," said Zanner, adding that any country forced to import these metals suffered severe disadvantages. For the research, Sandia built the only large, fully instrumented research furnace in the nation. Research on vacuum-arc remelting, electroslag remelting, and similar processes was generic, enabling each consortium member to apply it to its own processes and products.

Flat panel displays presented another collaborative opportunity. Narath told the Senate Armed Services committee that Sandia had an advanced capability for developing field-emission cathode displays that could support development of the next generation of flat-panel displays for computers, calculators, and other products. Markets for the liquid-crystal display used in the 1990s were controlled completely by Japanese industry. Sandia entered CRADAs with industrial and university partners to assist efforts to improve the display efficiency of next-generation color plasma panels by modeling interactions between the plasmas and materials.

To advance flat panel display technology, and perhaps regain a market share for the United States, Sandia in 1993 opened the National Center for Advanced Information Components Manufacturing funded by the Defense department and managed by Jim Jorgensen. There, Sandia and its partner laboratories, in cooperation with industry, pressed development of flat-panel technology useful for defense and leading to consumer products such as high-definition television and display panels that might hang on walls like pictures, or even roll up like window shades. Referring to this initiative, Walt Worobey of Sandia's electronics group observed, "The Jetson's era is slowly becoming a reality."

In late 1991, President Bush announced formation of a Partnership for a New Generation of Vehicles (PNGV) that included universities, the national laboratories, and General Motors, Ford, and Chrysler. This partnership sought to develop comfortable, low-emission automobiles that could operate

In a Sandia clean room in 1994, Walter Worobey examines a flat panel display pattern that might become useful in a variety of video displays.

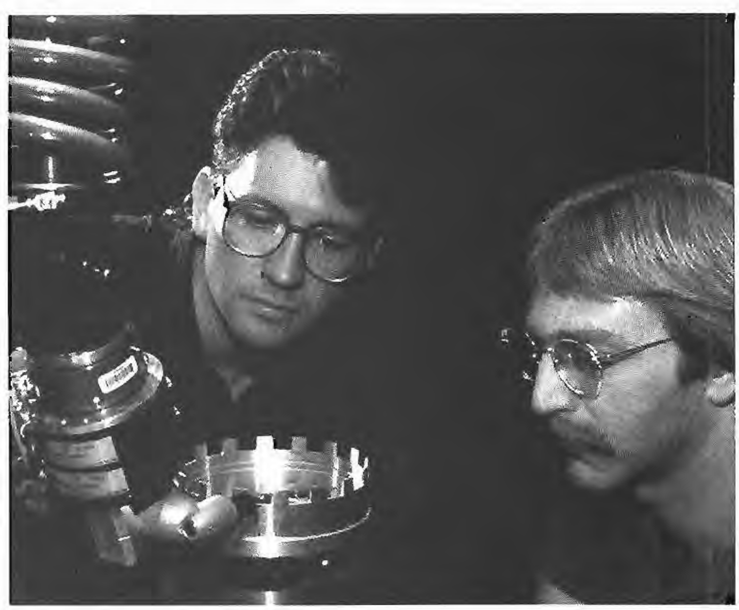
Al Narath in 1992 welcomes automotive executives to Sandia. *Seated left to right:* Thomas Moore of Chrysler, Donald Runkle of General Motors, William Powell of Ford.

One of Sandia's non-lethal weapon technologies that received wide media attention was the "goop gun" that sprayed sticky foam, designed to help law enforcement in the control of unruly prisoners. Jeff McDowell demonstrates its use.

Left: A Sandia technician inspects a chemical vapor deposition machine used for semiconductor research in alliance with SEMATECH, an industrial consortium.

Above: Under a cooperative research and development agreement with Rockwell International, Jim Novak designed this mast sensor to assist in the production of rocket booster chambers.

Below: Colin Selleck and Cliff Loucks inspect the precision cutting robotic system they helped develop for manufacturing.

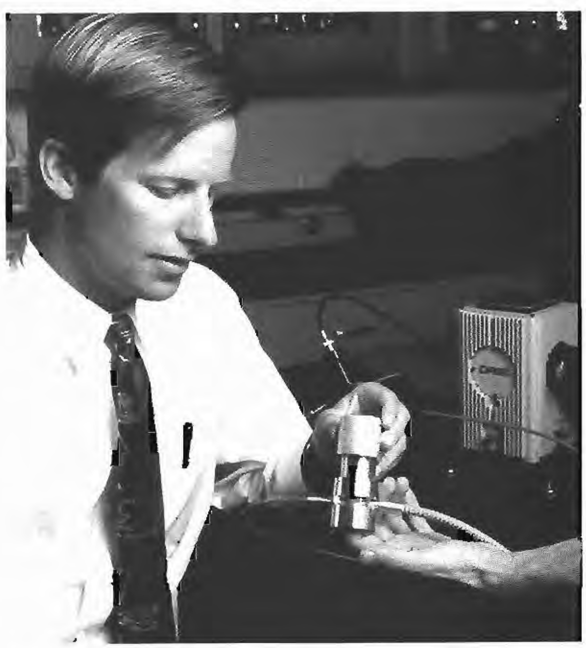


at an economical eighty-miles per-gallon by 2003. Sandia had worked closely with automakers for more than a decade at its Combustion Research Facility, and initial PNGV funding of $25 million expanded this cooperation. "Sandia will contribute to groundbreaking research on automotive materials, reduced emissions, batteries, and supercomputing," said Clarence W. "Bill" Robinson of Sandia California. This program grew throughout the early 1990s as U.S. automakers sought an economical, environmentally friendly, and "smart" car that might regain market share from imports.

By the end of 1994, hundreds of CRADAs and a growing number of pre-competitive

Rodema Ashby, *seated,* and Han Lin, *standing behind her,* demonstrate Sandia-developed conferencing software at a 1993 technology transfer exhibit in the U.S. Senate Office Building. Jim Yoder, of Sandia's engineering integration center, and Senators Pete Domenici and Jeff Bingaman look on.

programs with consortia brought Sandia's technology transfer efforts to nearly six percent of its total annual budget. By 1995 that share had grown to nearly eight percent. This rapid growth helped offset declines in Sandia's defense programs funding. Although but a small percentage of its total effort, Sandia's research and development in such arenas as transportation, law enforcement, and health care brought Sandia greater media acclaim than ever before. "Today we understand that national security is made up of a military dimension, an energy dimension, an environmental dimension, and a competitiveness dimension," Narath commented. "They're all intertwined and have a common technical foundation."



Ries Robinson of the University of New Mexico School of Medicine examines a non-invasive glucose sensor developed jointly with Sandia. Diabetic patients could use the sensor to monitor glucose concentration in blood with a beam of light, instead of drawing blood samples.

In recognition of the recommendations of the Galvin Commission in February 1995, that the national laboratory system "concentrate on fulfilling its traditional assignments in national security, energy, the environment, and fundamental science, while seeking industrial agreements that are part of the traditional cope of work," Sandia focused its partnerships with industry toward primary mission responsibilities. Paul Robinson's testimony before the Senate Armed Services Committee in March 1996 noted that "the technology bases for government and commercial needs are rapidly converging; ... collaboration with industry and universities is essential for the DOE laboratories' mission success. Sandia's progress in establishing mutually beneficial relationships with the private sector is evidence of substantial congruence between its essential core competencies and those of industry." The partnership of Sandia's weapon parachute designers with Precision Fabrics Group, Inc., which jointly developed a revolutionary automotive airbag that reduced weight and volume by sixty percent while strengthening Sandia's capabilities in developing and packaging high-performance lightweight parachutes for defense missions, is a classic example of these synergistic partnerships. In 1996 Sandia established as one of eight corporate objectives, "strategic partnerships with industry segments that are critical to [its] missions," because experience indicated that both the Labs and its private sector partners receive significant leveraged benefit from working together on common technology challenges.

COMPETITIVE PRESIDENTIAL VISITS

Although toured by Vice Presidents Hubert Humphrey in 1966 and Walter Mondale in 1978, Sandia had not enjoyed a presidential visit since John Kennedy looked at its permissive-action link development in 1962. During the 1992 election campaign, Sandia welcomed both President George Bush and candidate Bill Clinton.

President Bush, accompanied by Secretary Watkins, came to Sandia on September 15 to examine some of its technology transfer achievements. He saw Sandia innovations such as the noninvasive glucose sensor for diabetics, a robotic vehicle for cleaning contaminated areas, a robotic edge finisher for precision manufacturing, and a swing-free gantry crane. Al Narath gave him a model of a farm plow created by Arizona sculptor Doug Weigel and inscribed with the legend "Swords to Plowshares." Inlaid in its wooden base was a piece of weapon casing bearing the serial number of a B61 nuclear bomb dismantled in accord with the President's orders in 1992.

After his tour, Bush took the podium outside Sandia's Building 800. Thousands of Sandians in the audience cheered when he said, "I stand before this wonderfully productive and patriotic audience and say something no President has ever said before: the Cold War is over and freedom finished first." In Bush's opinion, the "defining challenge" of the future was to win the economic competition, to assure that America remained both a military and economic superpower in the 21st century. He announced major additional funding for nuclear non-proliferation programs to further this goal.

Three days later, Presidential candidate Bill Clinton arrived at Sandia, where he toured the Microelectronics Development Laboratory before speaking at a colloquium in the Technology Transfer Center. As governor of a state with industries struggling to compete in tough global markets, Clinton thought it "absolutely imperative that we have a national economic strategy which includes a technology policy that permits us to take advantage of every resource we have in this country, especially the national treasure represented by our labs." Offering his personal advice to Sandians, he said, "You have to be at the core of not only maintaining our national defense but promoting our national economy."

President Bush greets Sandians in September 1992.

When Bill Clinton visited Sandia during the 1992 election campaign, Al Narath described Sandia's development of a sensor allowing diabetics to monitor their glucose levels. *Left to right:* Clinton, Los Alamos director Sig Hecker, Narath, Dave Haaland of Sandia's materials reliability department.

At the time of these visits, Sandians were quite apprehensive, not about competition in the November election race, but about their own future. In May 1992, after more than forty years as the nonprofit contract operator and sole owner of Sandia Corporation, serving under ten Presidents and every elected Congress since November 1949, AT&T had announced that it would not renew its operating contract with DOE.

DIVESTITURE AND COMPETITION

Although many Sandians were surprised when AT&T announced that it did not wish to continue managing Sandia after its contract expired in 1993, there were signs beforehand that this might be the decision. Practically all of the original contract operators for DOE installations had withdrawn during the 1980s. Like AT&T in the case of Sandia, the DuPont company had accepted President Truman's patriotic challenge to build and operate the Savannah River plant as a public service, and like AT&T it had refused to accept a profit on the task. When DuPont withdrew from Savannah River's management in 1989, AT&T became the sole remaining no fee, no profit contract operator in the DOE system.

Several sound business reasons lay behind AT&T's decision to withdraw. As a vertically integrated regulated monopoly in 1949, AT&T had been one of the few firms capable of managing an enterprise such as Sandia, and accepted the challenge as a public service. As a result of divestiture during the 1980s, AT&T was no longer vertically integrated, nor a regulated monopoly, and other firms had demonstrated abilities to manage DOE installations. Moreover, during the 1980s Congress repeatedly considered making DOE contract operators legally liable for damages, and questioned why AT&T should risk losses for a nonprofit service.

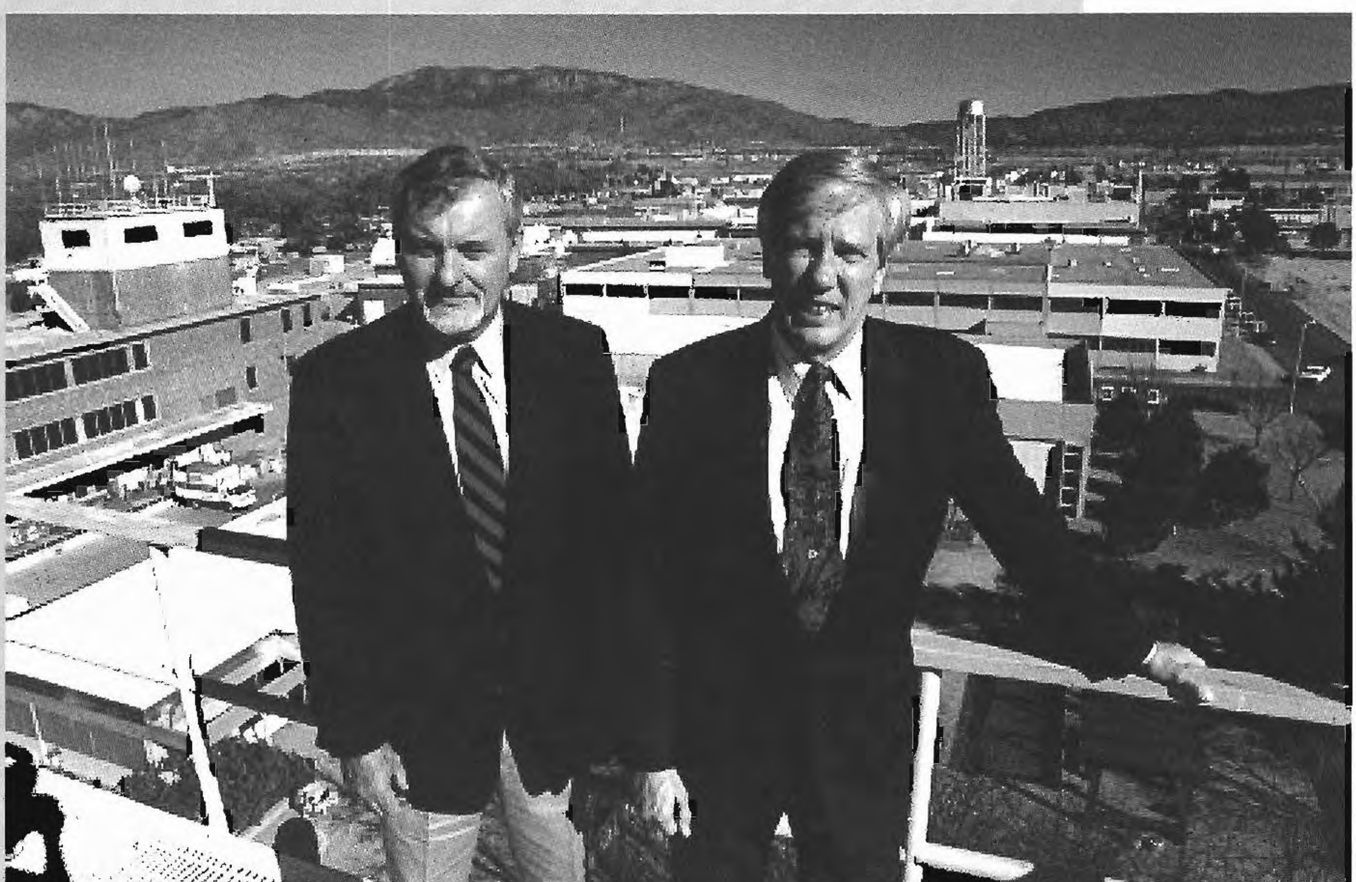
In October 1992, DOE advertised open competition for all qualified bidders wishing to make proposals for managing Sandia. More than seventy firms, universities, and institutes expressed interest in what the media dubbed the "Sandia Sweepstakes," and in January 1993 seven submitted formal proposals. After DOE winnowed these, it requested best and final offers from two candidates, Battelle Memorial Institute and Martin Marietta Corporation. Battelle, a nonprofit research institute, managed DOE's Pacific Northwest National Laboratory, and Martin Marietta, a defense aerospace firm, managed DOE facilities in Oak Ridge, Tennessee and Paducah, Kentucky.

Denny Krenz of DOE Albuquerque Operations chaired the DOE source evaluation board that selected Martin Marietta as Sandia's new contract operator in July 1993. Unlike previous contracts with AT&T, the contract with Martin Marietta included a variable profit, estimated by the media at up to $10 million yearly. As had been the case with AT&T, the contract was renewable at five-year intervals.

By merger with General Electric Aerospace in 1993, Martin Marietta became the largest aerospace and defense electronics company in the nation. Founded by Glen Martin in 1909, the company built aircraft during its early years, notably the famous China Clipper and, as part of its World War II license to build Boeing-designed planes, the Enola Gay. It merged in 1961 with American Marietta to form Martin Marietta, headquartered in Bethesda, Maryland and built the Pershing, Sprint, and Titan missiles, in addition to rockets that carried the Gemini astronauts into space. Its Hellfire and Patriot missiles saw service during the Persian Gulf War. In 1984, it received the contract for managing DOE facilities at Oak Ridge, later adding DOE plants in Paducah, Kentucky, Portsmouth, Ohio, and Pinellas, Florida, and earning recognition for transferring technologies developed at DOE installations to the private sector.

Immediately after winning the contract, Martin Marietta's chief executives, Norm Augustine and Tom Young, who had worked with Sandia on defense projects early in their careers, visited Sandia to start the transition and to reassure Sandians about their future under new management. Because Martin Marietta's basic business supported national defense, Augustine told Sandians he and corporate management expected to take greater interest in Sandia's activities than had AT&T.

Lee Bray and Jack Hickman headed the Sandia team that worked to ease the transition in management. After forty-four years of public service, from President Truman to President Clinton, through hot wars in Korea, Vietnam, and the Persian Gulf and throughout a dangerous Cold War, AT&T left Sandia on the last day of September 1993. The following morning, Al Narath and Bruce Twining, manager of the DOE Albuquerque office, formally signed the new contract and raised the Martin Marietta flag in front of Sandia. "Today," Narath observed, "we close a chapter in Sandia's history."



In 1995, Al Narath became president of Lockheed Martin's Energy & Environment Sector and C. Paul Robinson was named the eleventh president of Sandia.

X

THE AGILE LABORATORIES

We feel that agile response with comprehensive capabilities is indicative of Sandia's outstanding characteristic — a passion to serve the nation.

Al Narath

How should nuclear weapons be managed? This question challenged the nation and Sandia National Laboratories no less after the Cold War than it did after World War II. With an end during the 1990s of new weapons development and nuclear testing, how should the smaller stockpile of existing weapons best be certified and maintained? If Sandia was no longer to perform its traditional weaponization mission, what should be its missions? Indeed, some in Congress questioned the need for nuclear weapon laboratories and for the Department of Energy itself.

The pace of international change during the 1990s was historic as communist rulers in eastern Europe lost their control, as the Soviet Union disintegrated into a commonwealth of independent states, and as the competitive hostility of the Cold War diminished. These sweeping changes were not without dangers. Norm Augustine, chief executive of Martin Marietta, told the Albuquerque Chamber of Commerce in 1994 that, although the end of the Cold War made the world safer, in some sense it seemed to make the world safer for small wars as well. "There are 27 wars going on as we sit here right now," he counted, "this is still a dangerous world."

During the mid-1990s, attention turned from controlling the nuclear arms of the two superpowers toward the fate of the nuclear weapons and technology possessed by the independent republics of the former Soviet Union and the dangers of nuclear proliferation and terrorism everywhere. To the great and pleasant surprise of Sandians, they found themselves assisting Russians with safe weapons dismantlement and hosting former adversaries hoping to establish cooperative technology transfer programs.

Substantial changes in the U.S. nuclear posture followed these historic events, and in 1992, for the first time since 1942, the United States had no new nuclear weapons under development. In an era of shrinking defense budgets and nuclear arms reduction, Sandia's ability to respond to changing national needs became critical. It needed to support an aging stockpile, provide increasing support for arms control and treaty monitoring, assist with weapons dismantlement both at home and in the former Soviet Union, and pursue production assignments as part of the smaller, more agile complex planned by the Department of Energy for the 21st century.

AGILE MANAGEMENT

During the contract management transition from AT&T to Martin Marietta, most of Sandia's corporate leaders returned to AT&T or retired, giving Martin Marietta the option of appointing new leadership. Al Narath remained as president with Jim Tegnelia, chief of the Martin Marietta transition team, becoming the deputy laboratory director. Tegnelia served in the Defense department during the Reagan administration before becoming Martin Marietta's vice president of engineering and business development. With this change in contract managers, Sandia executives Lee Bray and Orval Jones retired. At his

In October 1993 Security officers Louis Matthews and Jeff McCullough raised the Martin Marietta flag at Sandia's main entrance in front of Building 800. As the result of a merger, Martin Marietta became Lockheed Martin in March 1995.

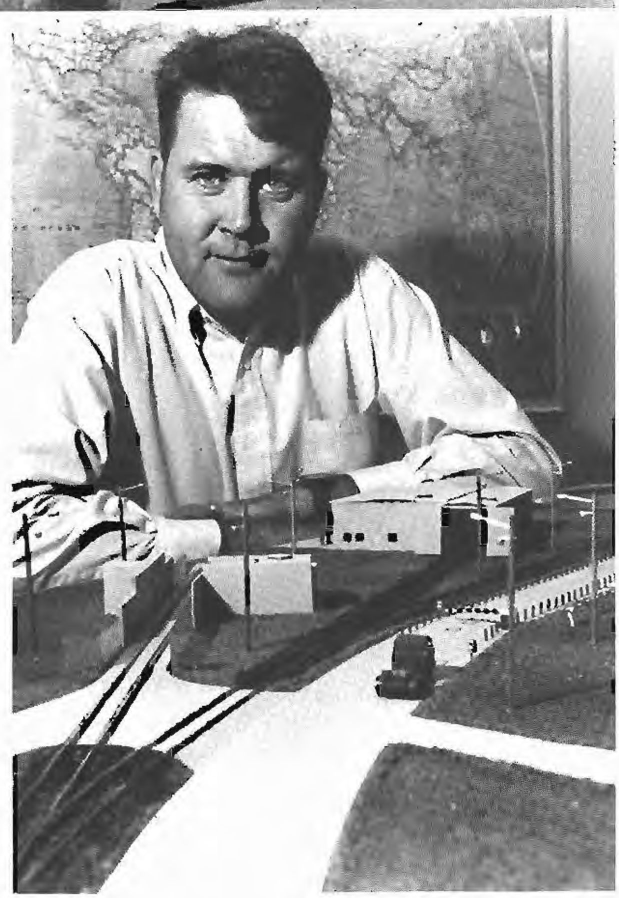
departure, Jones pointedly warned Sandians that they faced an uncertain future requiring them to leap from one technological pinnacle to another without losing balance. And as new weapon development ceased, many Sandia veterans made that leap, switching to energy programs, safeguards and security, facilities engineering, and the growing arms control and verification technology programs.

Tegnelia agreed with Jones that Sandia should survive in peacetime by serving national security in its broader sense. "I must emphasize that these national laboratories are not weapons laboratories, as they are so often called," declared Tegnelia. "For decades, we have been serving national security in a much broader sense than many in the general public realize. At the Department of Energy national laboratories, national security includes energy security, economic strength, and environmental integrity as well as traditional military security."

Tegnelia's observation seemed on target as several arms control treaties fostered the Cold War thaw, and Sandia had roles in negotiating those treaties. Larry Walker and John Taylor in Geneva provided information on verification technologies to negotiators for the Strategic Arms Reduction Treaty (START), while Jack Swearengen, Keith Johnstone, and Rick Beckman provided the Office of the Secretary of Defense with arms control advice on conventional arms limitation and Open Skies.

Signed in 1991, START limited the number of strategic delivery systems, the number of accountable warheads, and the number of deployed warheads. Intrusive, short-notice inspections of certain weapon production facilities were considered for treaty verification provisions, and Taylor prepared DOE installations by organizing and documenting full-scale on-site inspection training exercises. "We believe that to do this

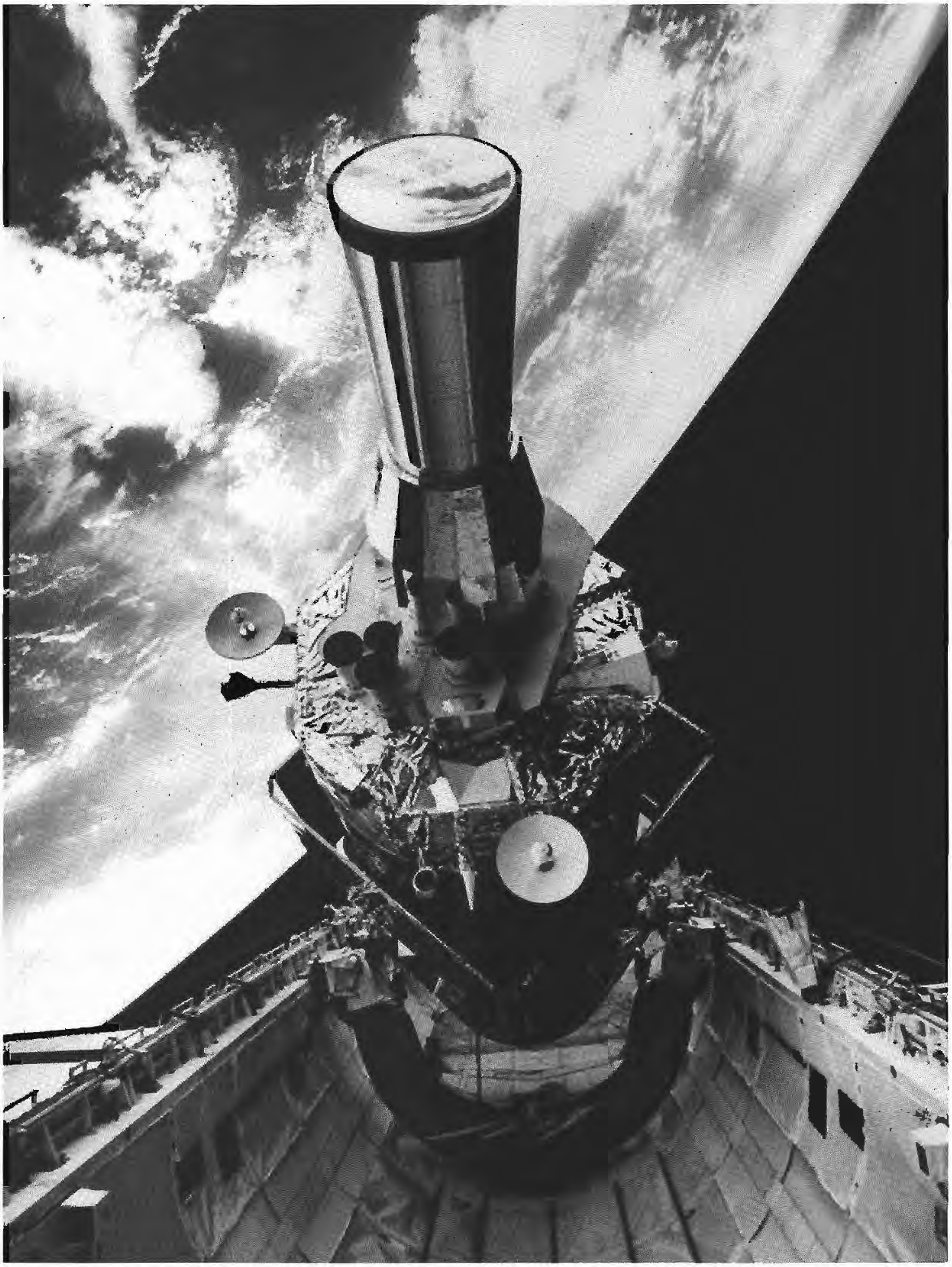
Above: Don Bauder applies a reflective tag designed at Sandia to a tank to assist in arms control treaty verification, while a crew films the operation and Keith Tolk, *left*, observes.



Right: John Taylor displays a scale model of the Technical On-Site Inspection facility developed at Sandia for INF treaty verification in the Soviet Union.

well is as important as building a good weapon," commented Roger Hagengruber.

Treaty protocols listed thousands of items to be monitored, and Sandia joined its partner laboratories in studies of emerging technology for this purpose as well as computer systems capable of tracking various weapons. Because many nuclear-tipped artillery shells were to be withdrawn from Europe, the Army requested Sandia's urgent development of a safe container to transport them. Cook Story, Robert Monson, and a Sandia team designed a stainless steel drum lined with redwood surrounding an aluminum container and tested it in jet-fuel fires and with air-drops onto concrete. By working directly with manufacturers and overseeing quality and schedules, Sandia delivered the container within six months as the Army requested.



In November 1991, a Defense Support Program (DSP) satellite equipped with Sandia and Los Alamos nuclear detection and environmental sensors prepares to leave the payload bay of STS-44 Atlantis 195 miles above the earth for the transfer to geosynchronous orbit at 22,000 miles.

"Arms control is an activity of growing emphasis," said Tom Sellers of Sandia's Remote Sensing and Verification Program, "and we intend to aggressively pursue the application of Sandia-developed technology." For example, with funding from DOE's Office of Arms Control, Sandia devised a method of counting warheads on missiles without removing the missiles from their silos or the warheads from their shrouds. In addition, when President Bush reintroduced the Open Skies concept proposed by President Eisenhower in 1955, allowing aircraft flights to monitor the movements of troops and munitions, Sandian Max Sandoval provided technical expertise. He explained that the Treaty on Open Skies, signed in 1992, aimed to reduce concerns about surprise mobilizations, especially in Europe. "Every time tensions are reduced in Europe," Sandoval observed, "that's one less skirmish that U.S. troops may eventually become involved in." For the monitoring permitted by the Treaty on Open Skies, the Defense Nuclear Agency asked Sandia and the Loral Corporation to redesign an existing synthetic aperture radar (SAR) to modernize it and make it exportable to all treaty signatories. The project activity, named the synthetic aperture radar for open skies (SAROS), produced a system to be flown on the open skies aircraft, the OC-135.

AGILE PARTNERSHIPS

Partnership with Russians was an event that Sandians had never expected to see, but it became reality during the 1990s. "The Russians have made commitments to dismantle nuclear weapons," explained Roger Hagengruber, "and while we are being careful to protect our own security interests, we are finding opportunities to help them."

Because the former Soviet republics had large numbers of nuclear weapons to move and dismantle, and the United States had a vital interest in seeing that these activities were accomplished safely, Congress responded with the Cooperative Threat Reduction Act of 1991. With funding from the Defense Nuclear Agency and other agencies, Sandia cooperated with the new nations. It supplied armored blankets for the safety of weapons on the move, and delivered emergency response equipment and provided training on its use. Sandia also developed protective containers for radioactive parts from dismantled weapons, provided kits to improve the safety of railcars moving the weapons, and worked with the U.S. Army Corps of Engineers to design storage facilities for the dismantled nuclear weapons in the former Soviet Union.

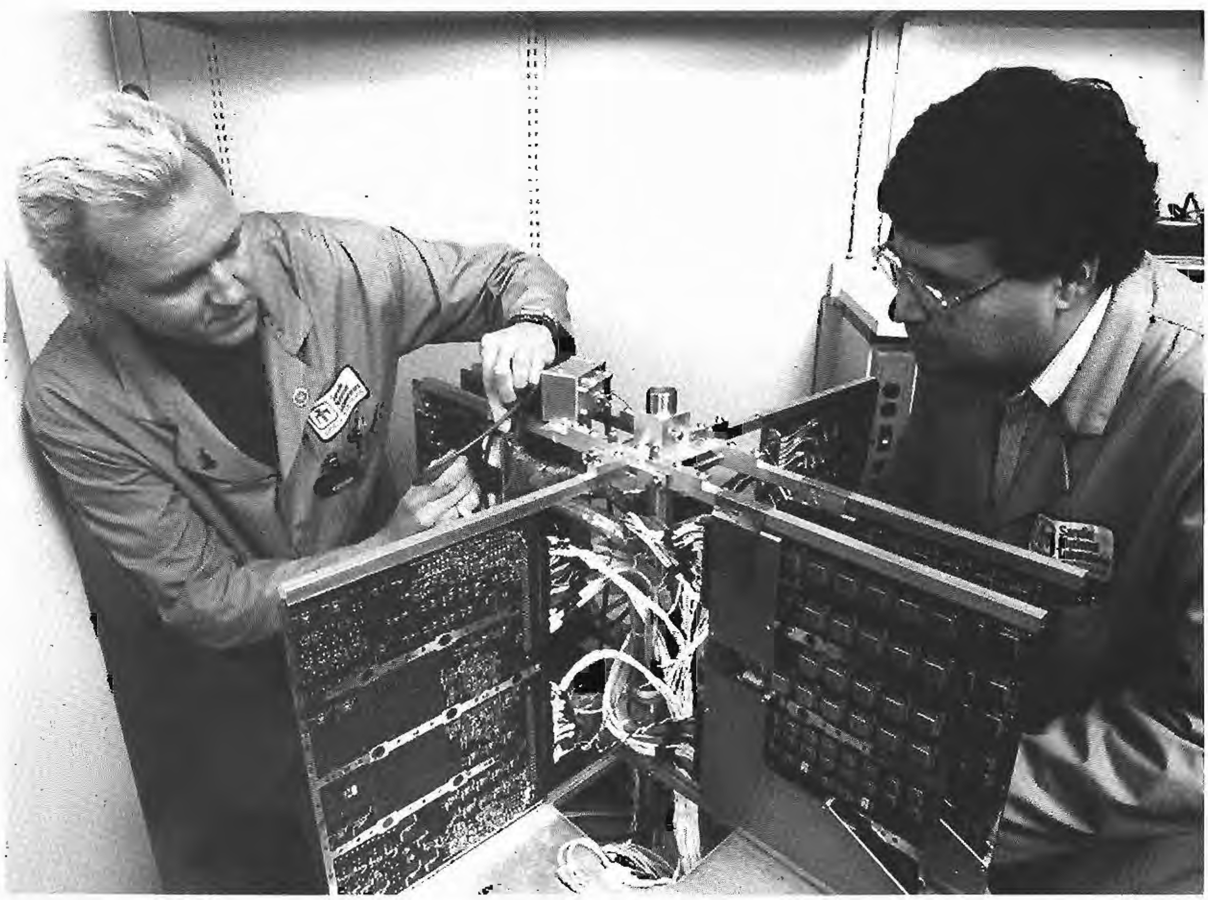
Congress funded programs at Sandia and other laboratories to collaborate with the former Soviet weapon laboratories and encourage the stabilization of those institutions in peaceful research. Sandia's goals were to support nonproliferation policies, learn about science and technology in the former Soviet Union, establish professional relationships with weapon scientists, and assist U.S. businesses seeking industrial partners in the newly independent republics.

It was little less than stunning to Sandians in 1992 when scientists from the Chelyabinsk-

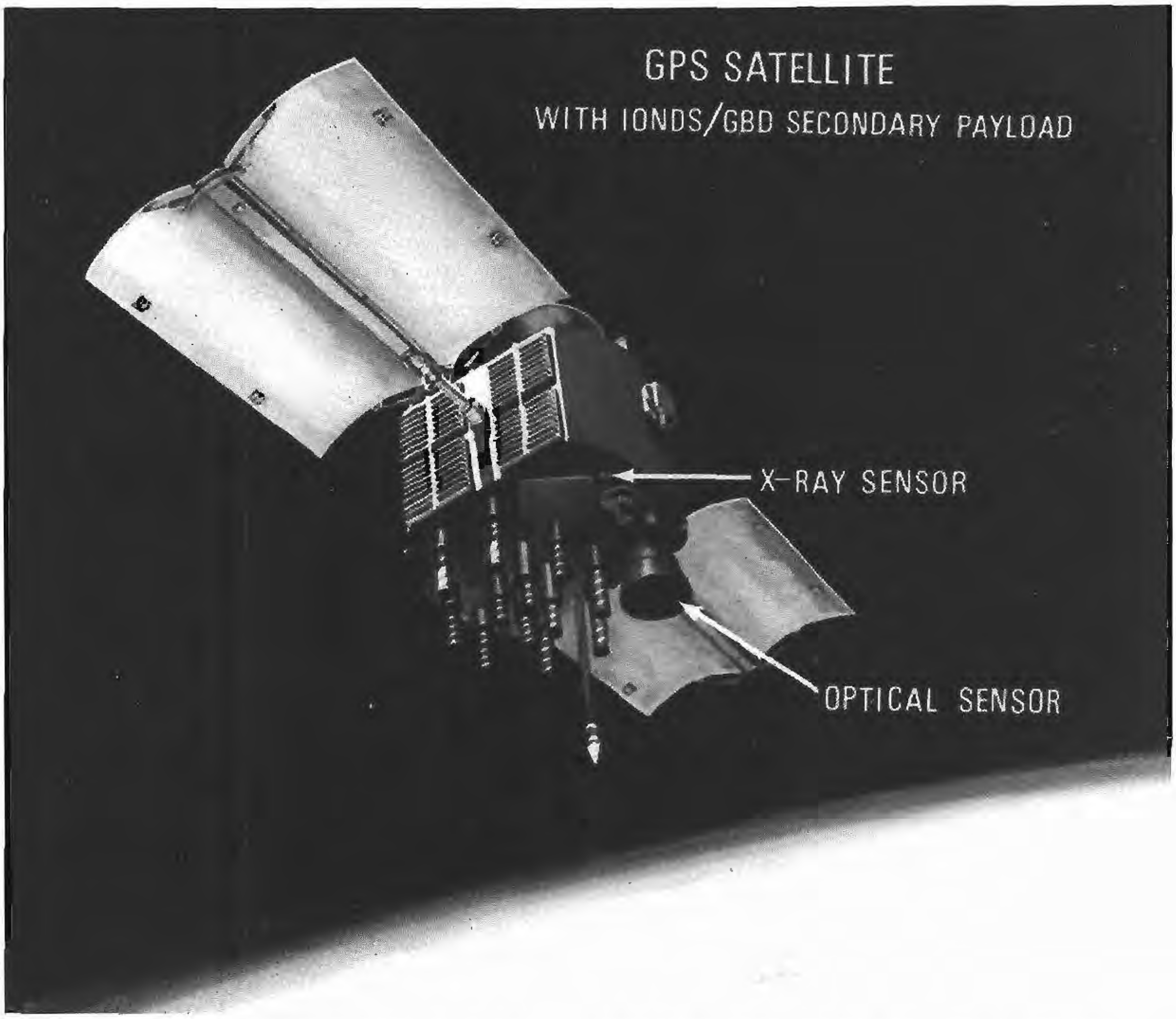
In November 1992, Roger Hagengruber, *right*, explains to Russian ambassador Vladimir Lukin the Sandia-designed container for transporting pits from dismantled Russian weapons.

70 and Arzamas-16 laboratories, the Soviet equivalents of Sandia, Los Alamos, and Lawrence Livermore, came to Sandia and, in an open forum, described the history and work of their laboratories. In turn, U.S. delegations visited the former Soviet Union's secret cities. Sandia negotiated research and development contracts with the Russian laboratories and worked with Russia and the states of the former Soviet Union to protect nuclear materials and weapons from illicit use and to convert defense technology to peaceful purposes. With assistance from the Technology Ventures Corporation in Albuquerque, Russian scientists started to learn about patents and approaches to technology transfer work as a prelude to entry into U.S. markets.

In light of the success of cooperation with Russian scientists, the State department in 1995 requested that DOE promote collaboration with China in arms control and verification technologies, nuclear materials safeguards, and nonproliferation. In a few months, Clyde Layne and Dave Nokes of Sandia, along with representatives of Los Alamos and Lawrence Livermore, were meeting in Beijing with the Chinese Academy of Engineering Physics (CAEP), the Chinese equivalent of the three U.S. nuclear weapon laboratories, to schedule workshops. During 1996, the China lab-to-lab program sponsored four workshops — two in China and two in the U.S. These included a workshop on cooperative monitoring technologies and applications held at Sandia, which was attended by seven Chinese scientists. Following the workshops in China, Sandia, Lawrence Livermore, and Los Alamos participants toured CAEP facilities at their Science City near Mianyang in Sichuan Province. This was incredible, indeed, to Cold War veterans everywhere.



Raivo Leeto and Jaime Gomez check an electromagnetic pulse sensor for detecting atmospheric nuclear tests that was packaged for use on global positioning system satellites to assist treaty verification.



A global positioning system satellite with sensors for verifying compliance with test-ban treaties. Twenty-four of these were launched during the 1980s. The optical sensor, power conditioning, and data processing components were provided by Sandia.

NONPROLIFERATION

"A very unsettled world with regionalism, growing ethnic and religious confrontations, and a huge inventory of weapons and nuclear material in an unsettled former Soviet Union," said Roger Hagengruber, "are the elements that have raised nonproliferation to a priority for our government."

Sandia's deployable seismic verification system for detecting underground nuclear explosions was installed in Wyoming for evaluation.

Sandia was well positioned to contribute to demands for reducing the prospects of nuclear proliferation. When the Non-Proliferation Treaty was ratified in 1970, Sandia had already developed technologies to protect nuclear materials from falling into unauthorized hands. This program grew to include systems for monitoring the movement and storage of nuclear materials, for detecting tampering with materials, and for transmitting sensitive data securely. For the International Atomic Energy Agency, as an example, Sandia developed unattended containment and surveillance instruments such as closed-circuit television, activity sensors, and tamper-protection devices.

VELA satellites with nuclear monitoring instruments designed and produced by Sandia and Los Alamos had monitored the atmosphere and outer space for nuclear explosions since the 1960s. The Defense Support Program (DSP) early missile warning satellite continued the VELA capability, again with Sandia and Los Alamos instruments known as RADEC for Radiation Detection Capability. In all, there were twenty-three DSP geosynchronous satellites planned to provide nuclear detonation surveillance as the secondary mission (missile warning being the first) well into the 22nd century. In the late 1980s, the Global Positioning System (GPS) satellites began to accept the space-borne nuclear detonation monitoring mission and would carry it past the lifetime of the DSPs. GPS satellites carried nuclear-detonation detectors designed at Sandia, and these furnished continuous, worldwide capability for detecting atmospheric nuclear explosions. Together with the data acquisition and display systems designed at Sandia, this system could verify atmospheric testing in violation of test ban and nonproliferation treaties.

Tom Sellers became Sandia's manager for nonproliferation and joined Bill Childers in

Sandia's nuclear weapons use control and permissive-action link system developed during the 1990s for the U.S. Strategic Command (STRATCOM).

Training the military services in control and safety for nuclear weapons has been a Sandia mission since the 1940s. This view shows Don Benoist briefing Air Force personnel about the B61 in 1990.

assessing overseas technologies. Sandia studied conversion of its satellite detector systems to make them useful as well for detecting chemical or biological weapons and missile testing. In addition to satellite-borne systems, cooperative studies with Sandia's partner laboratories included ultraviolet light detection and lidar ranging, radiation detection sensors, remote video surveillance, and nondestructive determination of particulate compositions. These sensors could be incorporated into unattended and remote ground-based systems. "This is clearly," Hagengruber said, "a future major strategic priority for Sandia."

Nonproliferation also encompassed efforts to reduce regional conflicts, and Sandia in 1994 opened a Cooperative Monitoring Center (CMC) for DOE to host visits by arms control specialists from throughout the world. "The basic idea," said CMC program manager Arian Pregenzer, "is to use technology to help attain regional security, thereby reducing tensions that could motivate regions to acquire weapons of mass destruction." This prototype regional center informed visitors about treaty-monitoring hardware and data processing that could help build regional confidence that nations could detect mobilizations by other nations. In 1995, for example, this Sandia forum supplied information to representatives from China, Russia, South Korea, and Japan who were studying the potential for a nuclear-weapon-free zone in northeast Asia.

MODULAR WEAPONS

When the President and the military services canceled phase 3 engineering for the W82, W89, B90, and W91 weapons in 1992, Sandia for the first time had no active nuclear weapon development programs. Even during the 1963 reductions mandated by Secretary McNamara, Sandia had continued its development of the B61. Sandians such as

John Crawford predicted, however, that the Sandia weapon mission after 1992 would become increasingly critical as the nuclear stockpile aged and needed to be improved with safer, modern designs to meet "more demanding accountability, survivability, and quality assurance standards."

"If the future stockpile is to shrink in size and cost, but still be capable of providing deterrence against a rapidly changing threat," Al Narath observed, "modularity may become a priority." As an example, he mentioned the B61. Designed during the 1960s, the B61 was not intended to serve as a building block for a family of modular weapons, but Sandia during the 1970s had demonstrated in the TIGER program that, by adding a new nose and rocket-motor tail, the B61 might be transformed into an air-to-surface standoff weapon. During the early 1990s, Sandia's W61 studies demonstrated that components of the B61 could be used in an earth-penetrating weapon. Such a flexible design might well satisfy potential future mission requirements of larger bombs that were scheduled for retirement. What larger bombs could accomplish through higher yields, the W61 could do through penetration. "Modularity," Narath explained to the Senate Armed Services committee, "is extrapolation of the concept of standardization and reuse toward the goal of maximizing flexibility."

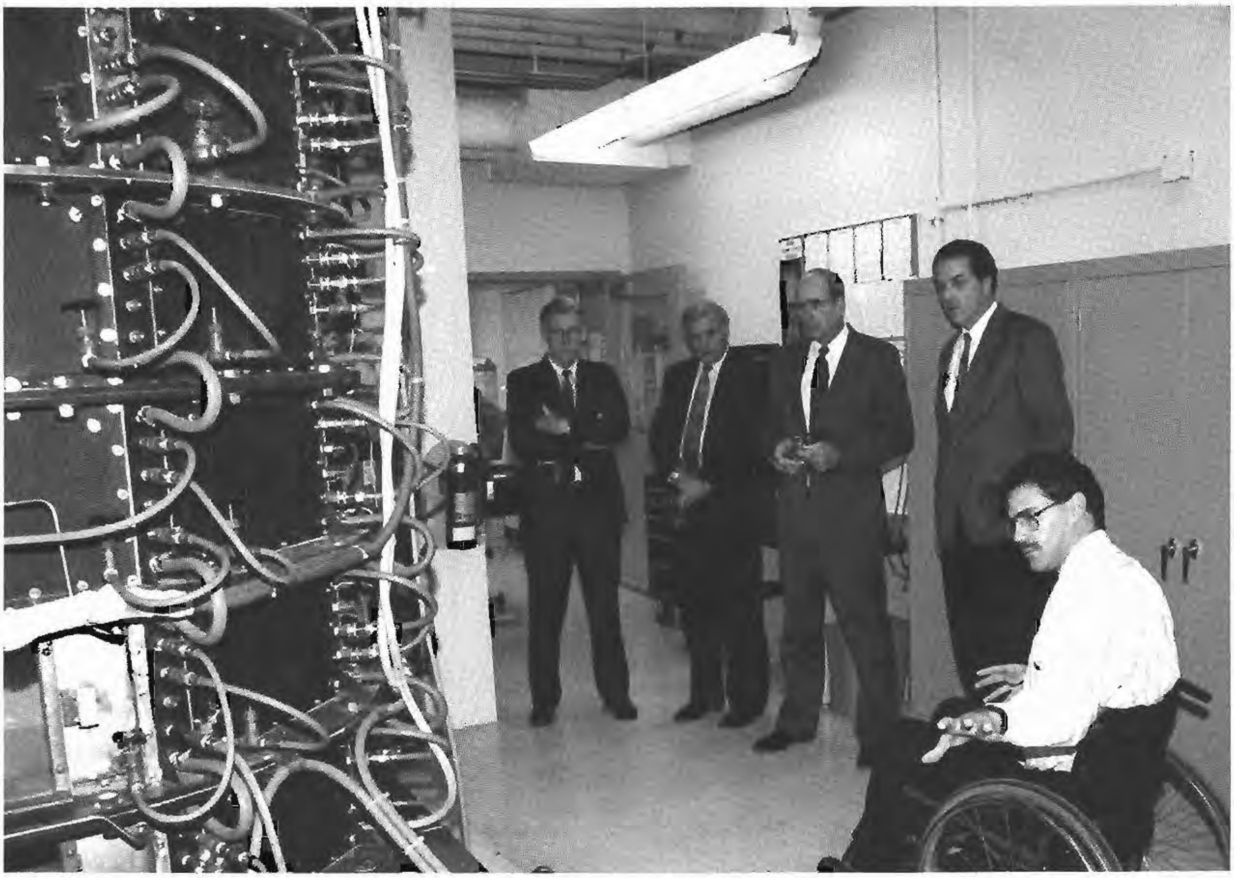
A major concern about the effects of aging on nuclear weapons was a reduction in yield, but precision delivery could render the magnitude of yield less important. The later-canceled phase 3 for the engineering development of a W61 earth penetrator began in late 1991. For it, Sandia used existing components of the B61 to reduce the development time, costs, and technical risks. The project's principal challenges involved designing a high-strength casing with modified components capable of withstanding the deceleration of driving into soils and hardened targets. A related Sandia exploratory project involved designing weapon casings made of composite materials that were stronger and lighter in weight than stainless steel casings, and these casings performed as designed during their initial tests. Another project involved modifying the B61 design to provide a standoff capability to make its delivery safer for aircraft and crew.

The smaller and aging stockpile carried stringent demands for reliability and for safety, security, and use control as well. Sandia and Los Alamos teams from the canceled W91 project joined in a warhead engineering effort called Multi-Application Surety Technology (MAST), focused on providing the latest nuclear surety technology for a smaller enduring stockpile. Stressing concurrent engineering, component production, and quality development tools, MAST concentrated on providing common electrical components and explosive packages for a family of warheads that could survive both laydown stresses and missile environments. Working with Lawrence Livermore, Sandia also participated in the design of the Pit Reuse Enhanced Safety and Security warhead, which incorporated advanced nuclear detonation safety and use control systems in a design that utilized pits reclaimed from retired weapons.

"At Sandia," Roger Hagengruber observed in 1995, "we have formidable and enduring responsibilities to assure that the policy options of the United States are never limited by the technology or condition of the stockpile in this period of change. We take those responsibilities very seriously."

AGILE PRODUCTION

With no ongoing development of new nuclear weapons, the Department of Energy planned to consolidate its aging production complex to meet smaller demand. It began closure of its Pinellas plant and Mound Laboratory and consolidated non-nuclear component production largely at Kansas City and Sandia. Increased manufacture of non-nuclear components by private industry figured in these plans as well, and DOE assigned Sandia a role in this "privatization."



Left to right: John Crawford, Jim Tegnelia, Norm Augustine, and Bill McLean listen to Neal Fornaciari explain Sandia's furnace research at the Combustion Research Facility in 1993.

During the dedication of Sandia's facilities for nondestructive testing of aging aircraft in 1993, Dennis Roach points out features inside a stripped Boeing 737. *Left to right:* Bruce Singer of the Federal Aviation Administration (FAA), Roach, Al Narath, Albuquerque Mayor Louis Saavedra, Representative Steve Schiff, Senator Pete Domenici.

During the early 1990s, Sandia reestablished a manufacturing engineering group managed by Harry Saxton to demonstrate the production of non-nuclear components by the commercial private sector. Sandia identified qualified vendors and transferred to them the technology needed to produce the desired components. This assignment further expanded with closure of the Mound and Pinellas plants. After a successful demonstration in 1993, DOE tasked Sandia to provide all microelectronics, frequency and magnetic devices, pyrotechnic devices, thermal and chemical batteries, capacitors, explosive-to-electronic transducers, and ceramics for nuclear weapons.

For the production complex, Sandia conducted a program managed by Joan Woodard to develop environmentally conscious manufacturing technology. Its emphasis was on reducing the use of hazardous solvents, reducing waste disposal costs, and protecting worker health. Sandia's Center for Solder Science, for example, devised manufacturing processes that would permit phasing out the use of chlorinated and fluorinated solvents as required by the 1990 Clean Air Act while at the same time improving the reliability of soldered joints used by private industry as well as in weapon production.

Heinz Schmitt managed Sandia's participation in a national effort called Agile Manufacturing to encourage the rapid production of small lots. Sandia explored the use of intelligent machines and robotics, concurrent engineering, real-time communications, and rapid prototyping; techniques that were useful to the production complex as well as in the private manufacturing arena. A four-building complex at Sandia California, first designed to test SDI systems, became in 1992 an integrated manufacturing technologies laboratory. Its purpose was to demonstrate and prototype agile manufacturing, the ability to switch rapidly from the production of one product to another while maintaining low cost and high quality. Roger Hagengruber described this as a tremendous opportunity to serve the national interest. Sandia would develop techniques for flexible, low-cost, rapid product cycles for small-lot fabrication, and quality control methods along with improved worker safety, rapid information exchange, and fully integrated research-to-manufacture capabilities.

Because the smaller complex could not afford the overhead costs of earlier years, DOE made Sandia responsible for prototyping and small-lot fabrication of various components, such as the neutron generators formerly manufactured at the Pinellas plant in Florida. These devices, which provide the neutron pulse needed to initiate a nuclear explosion, must be replaced periodically in existing weapons, and Sandia would produce the few hundred needed each year to maintain the stockpile. For this assignment, Sandia in 1995 created a production group managed by Gary Beeler, absorbed some of the personnel from the closed Pinellas plant, and began modifying a building for the first actual production, excepting microelectronic devices, at Sandia since the end of the Road department in 1952.

Al Narath also announced in 1995 that Sandia was considering the production of medical radioisotopes at its annular core research reactor, formerly used for weapons testing. If approved, the reactor would be used to ensure the supply of molybdenum-99. One of the most widely used tools for health diagnostics, the sole North American source of this medical isotope was an aging Canadian nuclear reactor.

DIFFICULT VICTORY

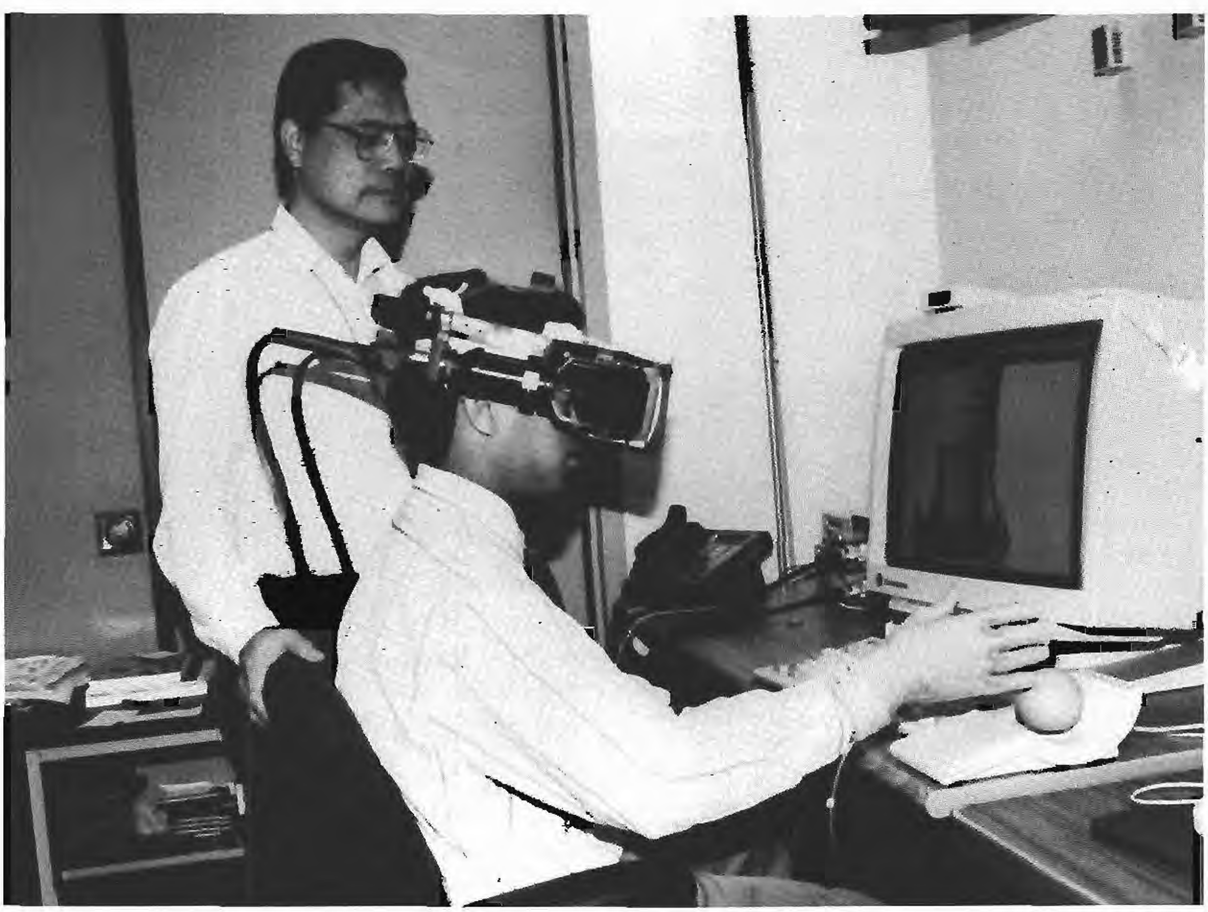
"Any time a radical change of direction takes place, like the one we've seen with the cessation of testing, you can expect significant impact on the people," commented Narath in 1994, "and they are people who have dedicated much of their careers to that work. I feel very badly for them. Sometimes victory is more difficult to take than the battle."

President Clinton in 1993 and again in 1995 extended the moratorium on nuclear testing begun by Congress. This directly affected Sandians participating in underground nuclear testing at the Nevada Test Site and challenged Sandia and its partner laboratories to develop alternatives to underground testing. In response, Sandia undertook two initiatives: expanding its above-ground simulation facilities, and improving its capacity for virtual testing, by using computers to mimic nuclear testing.

By the 1990s, Sandia had several above-ground simulators in operation. The Hermes III gamma-ray and the Saturn x-ray machines had proven useful in establishing design reliability, assessing system responses to weapon effects, and checking the radiation hardness of new components. Sandia therefore teamed with the Defense Nuclear Agency to plan a powerful new accelerator to generate soft x-rays, naming it Jupiter as a follow-on to Saturn. Although these machines could never fully duplicate the variable and synergistic effects of radiation from a nuclear blast, they could serve as excellent vehicles for radiation-hardness tests.

Winning several prizes for advances in massively parallel computing, Sandia became a world leader in supercomputing by the 1990s. During Bill Brinkman's tenure as vice president of research at Sandia in the 1980s, he had formed a new computer sciences directorate headed by Ed Barsis to address computing and intelligent machine issues and to perform calculations on a scale never before possible. Some experts were pessimistic about massively parallel computing — a thousand or more processors working on different aspects of the same problem simultaneously — but, in 1988, with a 1,024-processor hypercube computer, Sandia proved it could solve important engineering problems a thousand times faster than with a single processor.

Roy Lee watches David Andaleon work with virtual reality headgear and glove at Sandia's Virtual Reality Lab, exploring its use for computer-aided design in 1994.



Using innovative mathematical methods and algorithms, Sandia during the 1990s set new world records with parallel processing. This provided a computer-simulation capability that was especially important for assessing the safety and reliability of the aging weapons in the stockpile. Moreover, it could accommodate Sandia's complex hydrodynamic codes that earned wide acclaim in 1994 by modeling the impacts of the comet fragments that struck the planet Jupiter.

By 1995, Sandia was using the Intel Paragon XP/S, the world's most powerful production supercomputer, for weapon testing simulation. The Labs entered into an agreement with the Intel Corporation for development of a computer ten times more powerful than the fastest one operating in 1995. Designed to surpass teraflop speeds (a trillion floating-point operations per second), this computer was the early keystone in the DOE accelerated strategic computing initiative aimed at transforming nuclear design from actual tests to virtual simulation. To be located at Sandia, it would be used chiefly to simulate nuclear testing and ensure the safety and reliability of the stockpile. "It is a very important step," said Paul Robinson, "in shifting from a test-centered program to a computational-centered program." Recognizing the intimate relationship between simulation and testing, Sandia in 1995 merged its testing and computational simulation groups into a single information research and technology division managed by Gerold Yonas.

Sandia's powerful supercomputers found commercial applications as well. Sandians Paul Hommert and Bill Camp pointed out that they could be used for petroleum exploration. The petroleum industry had ships surveying with seismic and other instruments the potential sites of offshore oil reserves. These instruments generated terabytes of data that required months of analysis by most computers. Results on Sandia's Paragon demonstrated that this computer could accomplish the analysis in a day, allowing the ships to resurvey promising sites before leaving an area.

Taking their cue from the three-dimensional virtual reality games popular at video arcades, Sandians described computer simulation of nuclear tests as "virtual testing." This found an echo in the 1995 Galvin Commission report on the future of the national laboratories. It suggested networking computer systems among the ten multiprogram laboratories managed by DOE to create "virtual laboratories," which could share research data to reduce facilities costs.

STOCKPILE STEWARDSHIP

Sandia had served as a steward of the national nuclear weapon stockpile from its earliest days. In cooperation with its partner laboratories and the military services, Sandia quality assurance experts randomly withdrew weapons from the stockpile on a regular basis and evaluated their components in detail. This was a tool used to assess reliability, stockpile life, and to determine where improvements were needed. It constituted part of the "cradle-to-grave" responsibility in which Sandians took pride.

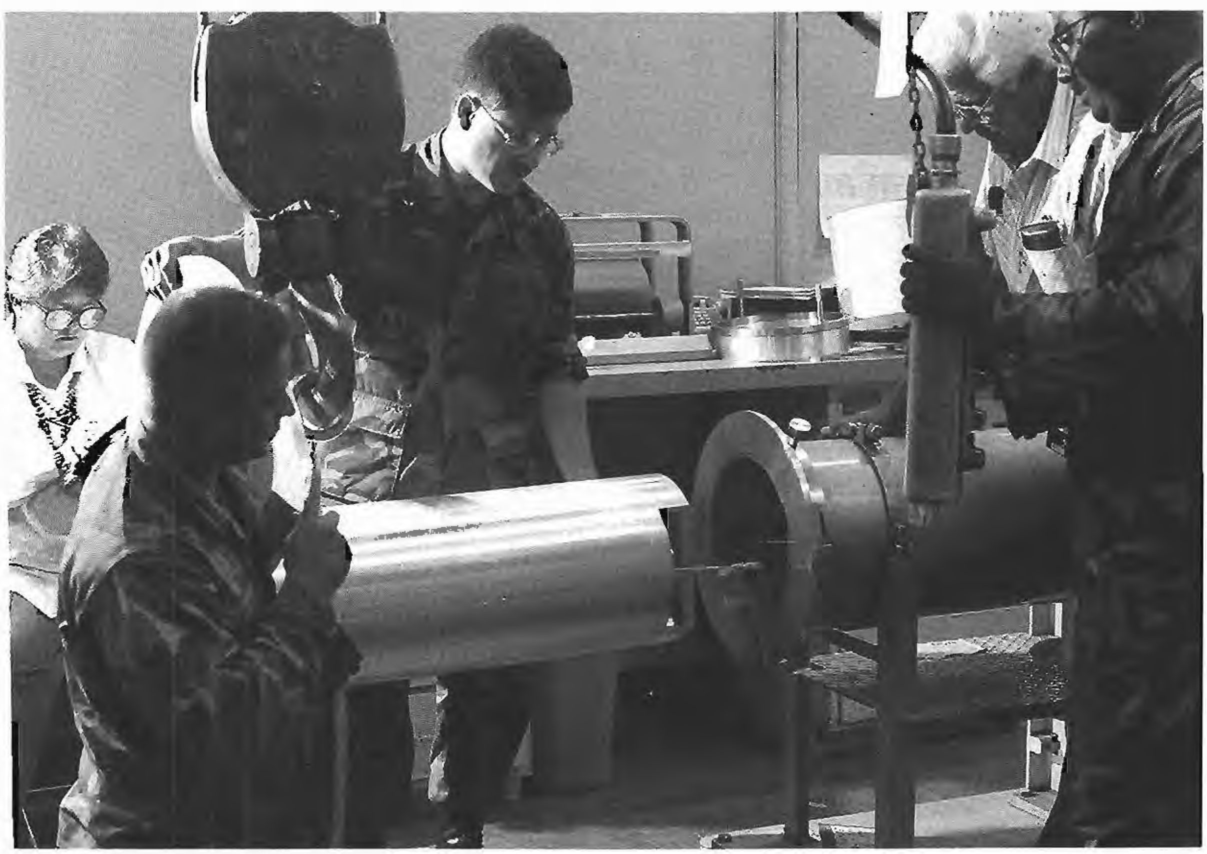
After shepherding nuclear weapons from their conceptual design (phase 1) through first production (phase 5), Sandia undertook stockpile evaluation (phase 6) to ensure through stockpile sampling and laboratory and flight testing that the weapons continued to meet their requirements. If the evaluations revealed deficiencies, Sandia provided specific solutions. "We've found cracked plastics, a silicon lubricant that was harming polyethylene cables, discovered some problems involving outgassing and corrosion — and a number of other difficulties," said Frank Muller of Sandia's stockpile evaluation group. "These were taken care of expeditiously with repair, retrofits, or new designs."

Sandia's initial stockpile quality efforts of the 1940s included inspection, audit, sample evaluation, and first production inspection. The introduction of sealed-pit nuclear packages, of environmentally sealed warheads, and of one-shot components reduced the need for field maintenance but precluded field testing of many components as well. To compensate for the lack of field-generated data, Sandia began its stockpile sampling program in collaboration with Defense agencies. Joint flight tests began in the 1960s to complement a wide variety of laboratory testing to ensure problem detection before the stockpile degraded. Thoroughly analyzing every test failure and anomaly, Sandians pinpointed the causes and expected impacts on reliability or safety, then proposed corrective measures.

Many laboratory tests were conducted at Sandia's field office at Pantex where the weapons were disassembled. Weapons selected randomly from the inventory, regardless of where they were deployed, were returned to Pantex where the safety and use control features were first tested and the internal gases checked through mass spectroscopy for chemical reactions. After these initial examinations, a weapon's nuclear explosive was removed for study by Los Alamos or Lawrence Livermore experts.

Sandia examined the arming, fuzing, and firing hardware, then configured it for laboratory or flight testing. For flight tests, Sandia used its Tonopah Test Range in Nevada and military test ranges as well.

For flight evaluation, Sandia installed an instrumented testing package with the same mass and dynamic response as the removed physics package. This created a Joint Test Assembly (JTA) with the same mechanical, electrical, and ballistic features as the weapon. The JTA went back to the military for reattachment to its original delivery system and testing in a realistic stockpile-to-target sequence. The military services then used operating carrier systems with standard operating procedures to deliver the weapon. In the case of bombs, this often occurred at Tonopah, where radar, optical and film recorders, and telemetry receivers were available for complete instrumentation of bomb performance in the field.



Sandia's military liaison writer Ellen Edge, *left,* documents the step-by-step details of a new procedure performed by Air Force weapons specialists assembling a B61.

Periodically, weapons are randomly removed from the stockpile, taken apart, and tested in a variety of ways. Some components are assembled in Joint Test Assemblies and exercised in test drops, as shown in this photo.

Sandia and Stockpile Evaluation

Credible nuclear deterrence requires weapons that work as intended without fail. Since 1948, one of Sandia's principal missions has been continuing assessment of the national nuclear stockpile's performance capabilities.

Until the first nuclear testing moratorium began in 1958, Sandia relied on extensive field testing of both inert and live weapons to assess their reliability, and field surveillance operations were conduced by military personnel under the supervision of AEC personnel. At the same time that the moratorium was curtailing some testing opportunities, the advent of sealed-pit weapons transformed the methods of ensuring reliability and safety. As a result, a new program involving the return of stockpile weapons to AEC for test and evaluation was implemented. Sandia began assessing the reliability of non-nuclear components through stockpile evaluation sampling, disassembling weapons to remove the fissile and explosives materials, and then testing the non-nuclear system in a laboratory to see if it functioned properly. Laboratory testing of inert weapons usually was done by Sandians stationed at the Pantex plant near Amarillo, Texas.

The first stockpile weapon sample returns were received in 1958 from the W25 and B28 populations. Most of the findings and defects discovered in these initial cycles were related to design and production. With the prospect of nearly 20 new weapon types entering the stockpile, the decision was made in 1959 to sample and test newly produced units to reduce the time before discovery of design and production defects. A weapon system was subjected to three different sampling rates for evaluation during its stockpile lifetime. The highest rate was during the first six months of production, followed by a combination of new material and stockpile samples for the remainder of production, and finally just the stockpile samples until two years before retirement when sampling ceased.

In 1963, DoD agreed to a Sandia-originated AEC proposal to include flight testing to address some aspects of the performance of the entire weapon system. At this time the evaluation program was also broadened to consider all of the conditions in which weapons in the stockpile were expected to function.

Concern over possible problems due to weapon aging was addressed beginning in 1970 when Accelerated Aging Units were first selected from production and subjected to accelerated thermal cycling patterns. This form of testing provided an early opportunity to discover material compatibility problems that escaped detection during development, production, and new material testing.

More recently, with no weapons in production, only the stockpile portion of the Stockpile Evaluation Program has remained active. Typically, eleven samples of each weapon type are randomly taken from the stockpile each year. These samples are subjected to some disassembly and inspection prior to testing, and the non-nuclear components are then assembled into a laboratory test bed for system level testing or into a Joint Test Assembly for flight testing. Although there are variations, in general the nuclear explosive package from one sample per year per weapon type is destructively examined for dimension and material composition changes by either Los Alamos or Lawrence Livermore. This sample is then retired from the stockpile. For the remaining ten samples, the non-nuclear components, which have not been destroyed during these tests, are reassembled into the weapon along with replacement parts (made during production for this purpose) and new nuclear packages and then the weapons are returned to the stockpile.

Sandia's mission to continually assess the nuclear stockpile's reliability has never changed. However, the methods for achieving that mission have been modified in response to changing national policy and evolving technological capabilities.

Sandia tested as many as a thousand weapons yearly during the 1960s, but improvements and economies in testing reduced the annual number by more than half in the 1970s and beyond. As Sandia's engineers came to rely less on field testing during design phases, and as the design of new weapons closed in 1992, Sandia confronted the issue of how to continue its stockpile testing during an era of constrained budgets. In 1992, for example, at the recommendation of Paul Robinson, the development of instrumentation for JTA systems was consolidated at Sandia California.

"Testing is, in fact, the heart of our engineering system," Hagengruber declared, but he warned that Sandia's testing facilities would shrink. Ruth David, Jim Powell, and Kathleen McCaughey managed reductions during the 1990s in field testing at Tonopah and in Albuquerque, by resorting to a "campaign mode" in which small operating staffs formed the nucleus for augmented staffing during testing.

For the foreseeable future, Sandia and its partner laboratories will continue as the nation's technical conscience for the nuclear weapon stockpile. The future stockpile will encompass fewer weapons and will rely on established designs. Because no new nuclear weapons were under design in 1995, the existing weapons would soon become the oldest stockpile in history. The institutional memory and continuity, the skilled experience, the engineering expertise for maintaining this stockpile resides at the laboratories. "We have known for some time that the nuclear weapons initially designed to be in the stockpile for 15 or 20 years may now be there for 30 years — maybe even longer," Hagengruber observed. "How materials behave when they're in a system for 30 or 40 years in contact with other materials over various temperature ranges is challenging technical territory, and this is an area where we can make major contributions."

With no new weapons being designed or built and no nuclear testing underway, the enduring national stockpile of a few thousand weapons of several types must last indefinitely. Sandia's challenge resembles parking an automobile in a garage for twenty years and assuring that it will start when needed. Just as an automobile parked for twenty years would show the effects of aging,

Keith Johnstone interviews Larry Humpherys at Sandia California for the Knowledge Preservation Project while Carmen Ward monitors.

Dismantlement of the last B57 was on February 24, 1995 at Pantex. Participating in the project were Mason and Hanger (M&H), Sandia National Laboratories (SNL), and Los Alamos National Laboratories (LANL). *Left to right:* D. W. Dollar (M&H), Tim Morris (M&H), Bobby Mack (M&H), William Weinreich (M&H), Paul Longmire (SNL), Jim Angelo (M&H), Robert Martin (SNL), Luis Salazar (LANL), Fred Edeskuty (LANL), Darrell Schmidt (LANL).

nuclear weapons can also degrade over time. Components can crack, helium impurities from radioactive decay can build up internally, high explosives can decompose. Sandians knew such deterioration could happen because they had seen it happen before.

To preserve the knowledge accumulated by the engineers and scientists who had designed and maintained the stockpile during the previous fifty years, Sandia in 1994 initiated a project to preserve their knowledge. Carmen Ward and Keith Johnstone began a series of interviews with Sandia's weapon program veterans to preserve the knowledge of their craft, for fear that its loss might leave the nation unable to maintain its stockpile, or to restart production if forced by international events. This Knowledge Preservation Project became part of the science-based stockpile stewardship program initiated by DOE to replace the test-based stewardship of underground testing days.

The science-based stockpile stewardship program aims to maintain confidence in the enduring stockpile by improving experimental and computational capabilities, advancing surveillance, manufacturing, and materials capabilities, maintaining system engineering infrastructure, and preserving a nuclear design and experimentation capability. Vic Reis, DOE Defense Programs manager, declared that this was the most challenging technical effort since the dawn of the nuclear age and warned that it would be "neither inexpensive nor without risk."

CRADLE TO GRAVE

"I never thought it would happen so quickly," reflected Roger Hagengruber, "but suddenly we are forced to live the dream and dismantle weapons faster than we built them." Sandia furnished direct engineering support to the production complex for disassembly, just as it had for manufacture, and it participated in the dismantlement of thousands of nuclear weapons under stringent new environment, safety, and health standards. Paul Longmire became Sandia's manager for dismantlement, establishing a field office to work closely with partners at the Pantex plant in Amarillo. Issues of safety, transport, storage, safeguards, personnel safety, and hazardous wastes had to be resolved rapidly to comply with treaties.

It was necessary to find a faster way of dealing with the hundreds of nuclear weapon parts that contained hazardous materials with strict controls on their storage and disposal. In 1993, Sandia developed a system to speed weapon dismantlement by using radiography to determine the precise location of interior hazardous materials and an abrasive water jet to remove them through precision cutting. Typically, this system could remove hazardous materials in less than two minutes.

Sandia performed quality evaluations for each weapon to be disassembled and applied its technology to resolve the challenges. It developed an automated robotic system to replace manual operations at Pantex, thereby reducing worker exposure to radiation. It found a method to remove explosive charges from the parachutes taken from laydown bombs and thereby permit commercial recycling of the materials.

In the spring of 1995, after a four-year effort, Jim Harrison's team, working with Pantex and Los Alamos teams, disassembled the last B57, the nuclear depth bomb fielded by the Navy in 1963. This milestone completed the first large-scale dismantlement project. In May, after disassembling as many as ninety warheads per month, the last W68 was also removed from the stockpile.

But retirement and dismantlement did not mean the weapons had reached their graves. Opening burial sites for defense and civilian reactor wastes became one of the most controversial challenges in the history of DOE and of Sandia. Bob Peurifoy aptly described this challenge as a "thankless job that must be done."

WASTE ISOLATION

Sandia had begun its technical geoscience studies for DOE at the Waste Isolation Pilot Plant (WIPP) in 1975, expecting to open it during the late 1980s to store low-level nuclear wastes from weapon projects. Delays occurred during the late 1970s, when President Carter proposed storing civilian reactor wastes at the site in addition to defense wastes. Funding was held up while Congress debated this proposal, finally deciding that WIPP would store defense wastes only.

Shaft drilling into the saltbeds began during the Reagan administration, and in 1983 underground test rooms were opened, enabling Sandia to conduct full-scale studies of salt creep, fluid flow, and simulated waste interactions with the salt. The site was ready to accept waste by the end of the Reagan administration, but in 1989 Secretary of Energy Watkins suspended the opening pending further safety studies.

While reviews of WIPP by the National Academy of Sciences, the New Mexico Environmental Evaluation Group, and other agencies continued during the early 1990s, Sandia conducted large-scale brine inflow tests, instrumenting a room in the saltbed to measure closure of the room, crack development, humidity, brine inflow, and pore pressures, thereby improving the analytical ability to predict the creep closure and brine seepage into the underground rooms. Sandia participated in the checkout testing of 1991 that resulted in readiness certification for the first shipment of waste to the site.

Although WIPP received readiness certification in 1991, litigation by the State of New Mexico over transferring the site from the Department of Interior to DOE delayed its opening. After Congress enacted the necessary land withdrawal bill, DOE decided not to send wastes to WIPP for any purpose until EPA certified that the site met applicable standards. As a result, Sandia's main role was to complete its experiments and prepare a 10,000-year performance assessment as part of a DOE compliance application. "The focus is on how safe is it

Darrell Munson and Leonard Krako stand in the center of a room designed to simulate all but the radioactive aspects of waste disposal in bedded salt. Room deformation, temperature, brine migration, and canister corrosion studies were conducted over a half dozen years in this and similar full-scale test rooms.

WIPP: THE 10,000-YEAR TRIP

In 1989, Wendell Weart drove Secretary of Energy James Watkins around the tunnels and underground storage bins of the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Left to right: Watkins, Weart; Governors Cecil Andres of Idaho, Roy Romer of Colorado, Bill Miller of Nevada; John Tillman, DOE WIPP manager.

Waste Isolation Pilot Plant

Ever since DOE decided in 1970 against considering the Kansas salt beds as the site of a repository for defense wastes, the search was on for other suitable sites. By 1975, the search had focused on salt beds that were about two thousand feet deep in southern New Mexico near Carlsbad, and Sandia was assigned to do the scientific investigations of this site. Wendell Weart of Sandia's underground test division took charge of the Waste Isolation Pilot Plant (WIPP) project, initiating drilling and geologic investigations near Carlsbad. "We have four tasks," said Weart. "Site selection and characterization, conceptual design of the plant, drafting an environmental statement, and scientific studies." A suitable site was found in salt beds that had been geologically stable for millions of years.

Sandia moved to employ geologists and geoscience specialists to meet the challenges of underground storage investigations. In its early weapon programs, Sandia had little need of geophysicists except at the Nevada Test Site. With its participation in the Plowshare program and the development of earth penetrator weapons, Sandia began developing expertise in ground shock, cratering, stemming, and geology generally; and its energy research into drilling technology, geothermal and magma heat sources, oil shale and coal retorting, and oil and gas recovery required additional geoscience capabilities. A geosciences research group was established by Orval Jones, under Bill Luth's leadership, in the late 1970s. With the advent of the WIPP project, Sandia moved into the forefront of geoscience research.

As the first project of its kind, WIPP provided a fertile field for investigators. Sandians tested the effect of heat on salt. They forced fluids through geologic formations to help determine site properties and check the routes of underground water. They examined waste decomposition that created gases such as hydrogen and CO_2, looking for safety hazards. They checked the rate at which brine corroded metal drums and looked at its effects on glass and ceramics. Among the findings was the surprisingly rapid rate of salt creep or movement into underground chambers, which Weart declared to be favorable because it would seal off the wastes faster.

Accuracy in calculating how the salt beds would react to mining and the heat produced by radioactive wastes became critical in predicting the project's success over the long-term — 10,000 years or more. Because the isolation of the wastes could be breached by drilling into the salt formation, a significant challenge is to warn future generations of the existence of the repository. Monuments will have to be placed on the surface to warn future generations of the repository's presence and potential hazards.

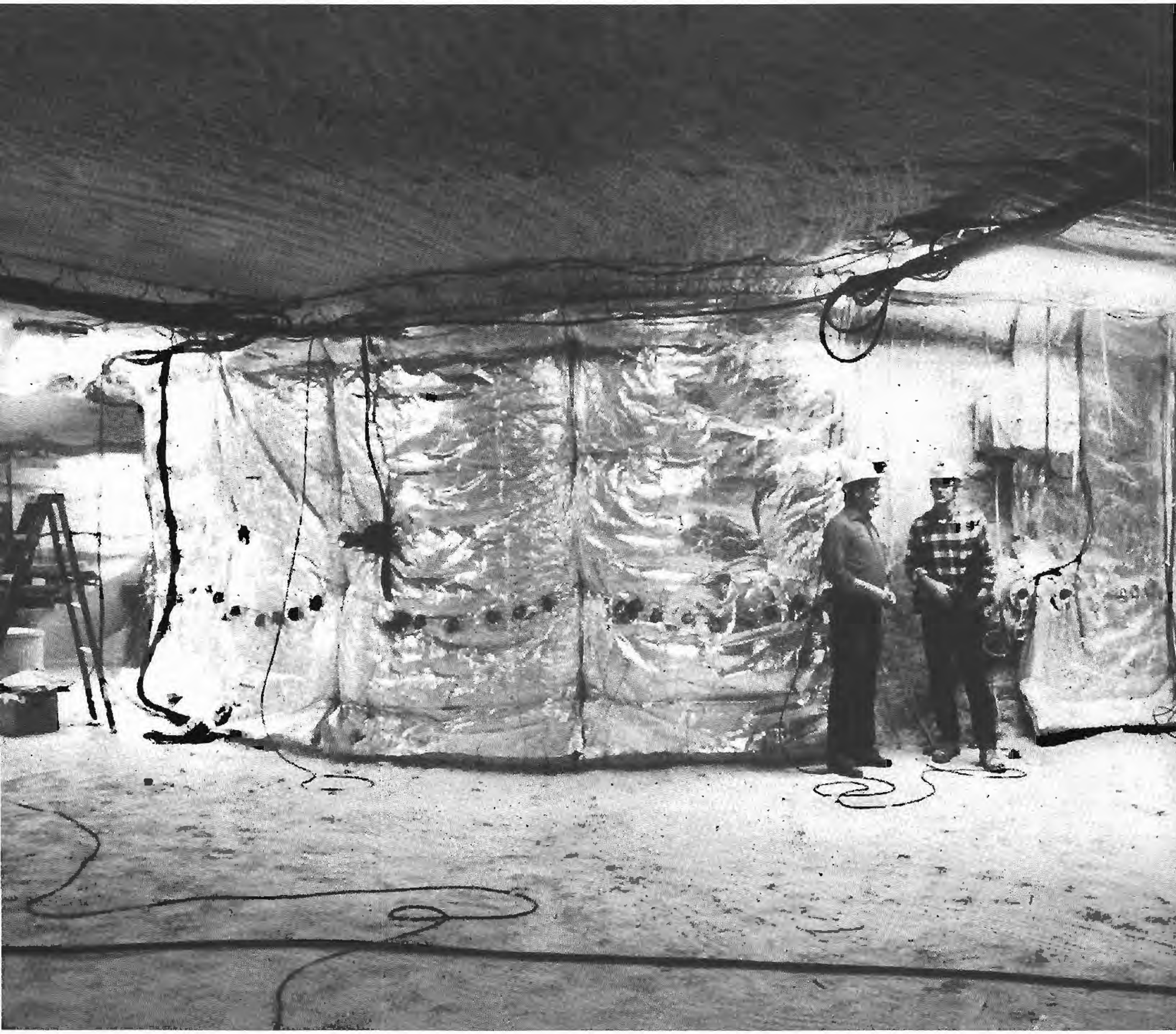
Because he managed Sandia's studies of storing nuclear wastes in deep underground salt beds, Wendell Weart was dubbed the "Sultan of Salt," although it is unclear where the designation originated, whether from the press or someone at DOE. Whatever the origin, Weart's superiors evidently agreed with the sobriquet: in 1992 he was named DOE Project Manager of the Year and in 1995 Secretary of Energy Hazel O'Leary commended him for his excellent work.

Weart's oddly cyclic career as a Sandia geophysicist began at the Nevada Test Site in 1959. For twenty years, he studied the ground motion and seismic signatures of underground nuclear blasts — information useful in detecting secret testing in violation of test-ban treaties — and the Nevada Test Site geology to assure that it could contain the radioactivity from underground tests. These responsibilities took him to sites outside Nevada where underground tests investigated the peaceful uses of nuclear explosives. Among these were the 1961 GNOME test near Carlsbad and the present WIPP project. During the GNOME experiment, Weart investigated the ground motion produced by the nuclear detonation in the nearby salt beds.

Weart returned to Carlsbad in 1974 when serving on the Governor of New Mexico's committee reviewing plans for a nuclear waste repository. In 1975 he managed the Sandia team that identified unpredictable geologic problems at the original site and moved the location about six miles to a site with stable geology. From studies of blast effects timed in milliseconds, Weart moved to studies of geologic stability during coming millennia.

After intensive geotechnical and hydrological studies, Weart and Sandia in 1980 recommended the WIPP site to the DOE for continuing investigations. In the following years, Sandia's WIPP team became, Weart said, "the recognized authorities in salt rock mechanics." In underground test rooms mined in the subterranean salt formation in 1983-84, Sandia's instruments recorded salt rock mechanics at various temperatures and explored such phenomena as salt creep and the interactions of salt with wastes. This information was vital to meet the requirements of regulatory reviews and to demonstrate that the repository can safely contain nuclear wastes for a minimum of 10,000 years, although Weart reports that Sandia's investigations indicate the WIPP site will survive for millions of years.

After twenty years as WIPP project manager, Weart became Sandia's senior science advisor for nuclear waste management, and his purview extended to the Yucca Mountain Project, a repository for high-level commercial reactor wastes, proposed at the Nevada Test Site where Weart's career began a third of a century earlier. Perhaps "a man for all ages" will replace "sultan of salt" as his press sobriquet.



Darrell Munson and Doug Blankenship stand in WIPP's rock mechanics test room. The circular room — 108 ft. in diameter with a 36 ft. cylinder of unmined salt in the center — provided data from an excavation of realistic scale to validate the rock mechanics model developed by Munson.

when you walk away from this facility," noted Lynn Tyler. "How do we contain radioactive wastes and keep them from entering the biosphere in 10,000 years?"

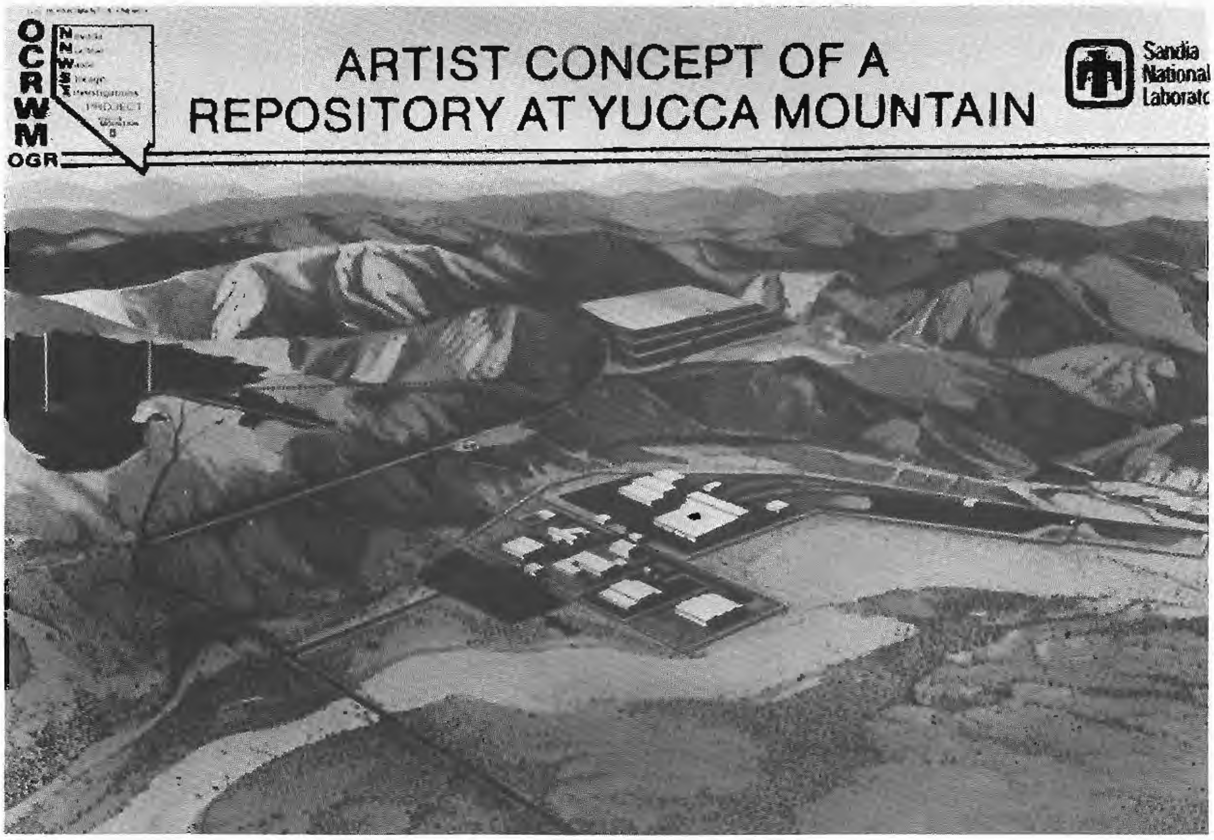
Shifting its efforts from experiments to regulatory compliance, Sandia in 1995 opened its WIPP operations center in Carlsbad for what began to appear to be a continuing assignment. Sandia's efforts in 1996 focused on incorporating 20 years of scientific investigations into a massive performance assessment of WIPP's behavior over 10,000 years, culminating in a Compliance Application to the EPA in October 1996. Vigorous adversarial debates in the media, courts, and Congress, in the meantime, continued over WIPP's opening. Calling the project delays ridiculous, Congressman Joe Skeen sponsored a bill in 1995 to open WIPP for storage in 1997, and Secretary of Energy Hazel O'Leary likewise announced her determination to open the project. "Until acceptable solutions are found — not just technically, but politically acceptable — I don't see much opportunity for growth," observed Narath at Sandia. "We play an important technical role in the Waste Isolation Pilot Plant project at Carlsbad and we have a similar role in the Yucca Mountain high-level commercial waste repository program."

Known originally as the Nevada Nuclear Waste Site Investigations Project and later as the Yucca Mountain Site Characterization Project, this project evaluated commercial reactor waste storage under a bone-dry ridge at the western edge of the Nevada Test Site. If opposition to WIPP was vigorous, adversaries to storage at Yucca Mountain were vehement, but this controversy lagged behind that at WIPP by a decade. Although Dick Lynch and a Sandia team initiated studies of the thermal, mechanical, and hydrological properties of tuff rock at the Yucca site during the late 1970s, it was not until 1987 that Congress, in a surprising cost-reduction initiative, assigned Yucca Mountain top priority as a potential storage site for high-level nuclear reactor waste.

Many Nevadans opposed storing reactor wastes in their state, and the state of Nevada raised legal obstacles to the Yucca Mountain site studies that went to the U.S. Supreme Court in 1991. A historian of Nye County, where the Yucca site was located, analyzed the political disagreements as follows: project supporters thought the Yucca Mountain site a sound choice given the area's desert climate and small population, along with the need to restrict access to the area for many years as a result of nuclear testing at the Nevada Test Site. Opponents emphasized the difference between the low levels of radioactivity from nuclear testing, compared to the high levels of the reactor waste to be stored at Yucca Mountain. They pointed out that most commercial reactor waste came from the Eastern United States and contended that Nevada, with the nuclear testing site and many military installations, had already contributed more than its fair share to the nation.

Tom Hunter managed Sandia's studies in support of the DOE Nevada operations office that investigated the Yucca Mountain site during the 1980s and early 1990s. These studies produced two large reports, the Site Characterization plan and the Conceptual Design report completed in the Sandia groups managed initially by Leo Scully, and later by Al Stevens and Joe Tillerson. Hunter asserted that the plans were to tailor the repository to conditions at the site, allowing for its geologic and hydrologic character. Rather than a vertical shaft as at WIPP, access to the storage area would be through a tunnel into the mountain. As Hunter described the plan, the tunnel would lead to underground chambers where the wastes would be stored in holes in the floors and walls. Remote-controlled robots would handle the wastes and retain the ability to retrieve them until permanent closure of the site about fifty years after waste emplacement began.

Working with DOE and its partner laboratories, Sandia had major roles in characterizing rock properties, modeling the site facilities, and producing conceptual designs for the exploratory studies facility under construction at Yucca Mountain in 1995. Sandians took special pride in their contributions to project performance assessment far into the future. When DOE in 1993 awarded contract management for the Yucca project to a consortium led by TRW,



Displaying Sandia's conceptual design report on the Yucca Mountain repository are Tom Hunter, Joe Tillerson, Al Stevens, and Hugh MacDougall.

Sandia's role switched to that of a subcontractor to TRW. To provide close support to the prime contractor, Sandia opened a small office at Las Vegas in 1993. Reflecting on the project's history, Tom Hunter observed that the search for the site and its development will have taken almost forty years when, and if, it opens as planned during the early 21st century. This span may not be exorbitant, however, considering that the site must serve for ten or more millennia.

AN AGILE FUTURE

Both Secretary of Energy Watkins and his successor in the Clinton administration, Hazel O'Leary, saw regaining public trust in the Department of Energy as a key to accomplishment of the WIPP and Yucca Mountain projects, along with other DOE programs. A 1992 DOE opinion survey revealed that public trust in DOE lay far below its level of trust in many other agencies. Commissioning a similar opinion survey in New Mexico, Sandia learned that, although a third of the citizens responding had no concept of Sandia's activities, most informed people trusted Sandia more than the media or local government.

As an effort to regain public trust, Secretary O'Leary in 1993 adopted an openness policy, releasing documents on human radiation experiments and forming a DOE office for declassification. In 1995, O'Leary created a panel to establish new classification policies allowing maximum public access without sacrificing critical national security. She named Al Narath to chair this panel of fifty experts including deputy chairman Glen Otey. Jim Wright and Dennis Miyoshi participated as leaders of two of the seven working groups and Bruce Green, Teddie Bruce, and Dick Craner provided significant classification support. O'Leary encouraged records declassification; but with about 130 million pages of classified records in DOE storage, of which Dick Craner

Secretary of Energy Hazel O'Leary in 1993 peered through a microscope at Sandia's micromotor. Paul Peercy and Senator Jeff Bingaman are behind her on the right, while newsmen enjoy the photo opportunity.

Sandians who assisted in the creation of a much-improved nuclear weapon classification policy guide, known as CG-W-5, for DOE and DoD. Shown in 1984, foreground, Nancy Barr and Wright Van Deusen; standing from left: Phil Mead, Frank Halasz, Dick Craner.

Security Classification and Sensitive Information Review Program

The overall mission of Sandia's Classification organization has been to ensure that Sandia National Laboratories employees and subcontractors are aware of and abide by DOE and other agency classification and unclassified-but-sensitive policies, procedures, and guidelines. This responsibility has been carried out in four ways: development and distribution of classification guidelines for Sandia classified programs, reviewing Sandia material intended for broad external distribution, consulting with Sandia line organizations on classification issues, and educating Sandia staff and management on their classification responsibilities.

Sandia's classification staff has been responsible for maintaining a delicate balance between identifying information that needs to be protected by classification, information that is unclassified but needs to be restricted in its dissemination, and information that is intended for public release. The bottom line — Keep Sandia National Laboratories out of trouble!

By 1996 there had been six managers of Sandia's Classification program — Classification Officers in DOE parlance. These were William Lawrence (1952-1955), William Smith (1955-1958), James Marsh (1959-1975), Lurl Ostrander (1975-1979), Richard Craner (1979-1996), and Joseph Morreale (1996-). The quality of the work in this office was reflected in the 1993 presentation to manager Dick Craner of a DOE Certificate of Excellence in recognition of outstanding service to the DOE Classification Program.

Before his retirement, Craner observed, "Sandia's Classification program has gotten much more complex as Sandia's technical programs diversified over the years." During Sandia's early years, when the vast majority of its work was nuclear weapons design and testing, most classified items fell in the category of Secret Restricted Data (SRD). Later, as work started in nuclear weapon use

In 1993, Bryan Siebert, Director of DOE Headquarters's office of declassification presented a DOE Certificate of Excellence to Dick Craner, manager of Sandia's classified and sensitive information department, shown here with his wife, Kathy.

control and stockpile maintenance, another category of classified information was added, Formerly Restricted Data (FRD), or that information associated with nuclear weapon military utilization. In later years, Sandia was responsible for Safeguards and Security and Work-for-Others programs. In these areas, classified information was categorized as National Security Information (NSI). "More recently," Craner said, " we have been involved with technical information that, even though it's unclassified, may require restrictions in its dissemination. Examples are Export Controlled Information (ECI) and Proprietary Information." A number of Sandia's unclassified programs, including Cooperative Research and Development Agreements (CRADAs), have required some information associated with the technology to be restricted in its dissemination.

Sandians have played key roles in the development of DOE classification policies on numerous occasions. During 1980-83, Sandia's Classification Office was part of a DOE task force to develop a Joint DOE/DoD Nuclear Weapon Classification Policy Guide (called CG-W-5) that incorporated a comprehensive rationale for making classification determinations. DOE Field Offices, LANL, LLNL, and DoD also participated. This was considered by DOE to be a significant step forward for nuclear weapons classification management and Sandians made major contributions to this effort.

Displaying the new Lockheed Martin Sandia Corporation flag in 1995 are Al Narath, Daniel Tellep of Lockheed Martin, Jim Culpepper of DOE, Norm Augustine of Lockheed Martin, Kathy Carlson of DOE, and Jim Tegnelia.

estimated about 25 million were at Sandia, the systematic declassification review would be a monumental task. Initial DOE funding for this effort was provided in fiscal year 1995.

In line with the openness initiative, New Mexico Senator Pete Domenici in 1995 called for Sandia's "walls to come down." By this, he referred to Sandia's effort to obtain a Gateway Center for visitors and an open entrance outside the Air Force security gates. This open center was to be located on Eubank Boulevard where Sandia was building facilities outside its classified fence in Albuquerque. "It's important for visitors to come and access this laboratory in a user-friendly way," said Narath. "The Gateway facility is the next step in the evolution of Sandia's relationship with the outside community."

To consider the future of Sandia and other national laboratories, Secretary O'Leary formed a Task Force on Alternate Futures chaired by Robert Galvin of Motorola and therefore commonly known as the Galvin Commission. After examining Sandia and other laboratories in 1994, the Galvin Commission released its historic report early in 1995. Highly critical of DOE, it also assailed the national laboratories after first admitting that "the entire nation owes a debt of gratitude to the women and men of these laboratories, past and present."

The Galvin report pointed to the sweeping geopolitical changes on the heels of the Cold War, to limitations on nuclear testing, to economic competitiveness, and to energy development and environmental quality as opportunities for the laboratories in the future. It suggested that the laboratories place renewed focus on their traditional missions for DOE and, in view of reduced international tensions and a declining stockpile, recommended transferring Lawrence Livermore's defense programs to Los Alamos. Its most striking proposal involved "corporatizing" the laboratories, perhaps in a format similar to the Federal National Mortgage Corporation or the U.S. Postal Service.

NATIONAL TUG OF WAR

President Clinton also had a study underway on the future of national laboratories, managed by Jack Gibbons, his science advisor. After reviewing the subject, the President in late 1995 announced that "the continued vitality of all three DOE nuclear weapons laboratories will be essential," and that his office would resist efforts to cut back the national laboratory system.

Congressman Steve Schiff of New Mexico explained that Sandia and other national laboratories were caught in a Congressional "tug of war" over their future. Some members of Congress advocated the formation of a Department of Science to include the laboratories. Others called for eliminating the Department of Energy and creating a national laboratories closure commission, and still others proposed transferring Sandia and its partner laboratories to the Department of Defense.

Amidst this sometimes confusing national debate, Sandia continued to change and seemed to prosper. Facilities manager Neil Hartwigsen reported in late 1995 that Sandia had more construction underway than at any time in its history. "It's huge," he exclaimed, describing the replacement of structures dating back to the 1940s with modern buildings to provide Sandia's infrastructure for the 21st century. He listed seven major structures under construction during 1995, each of them specifically approved by Congress as a capital line item in the budget, plus more general plant projects in progress than ever before. Clearly, Sandia would have a much improved physical plant as it entered the 21st century.

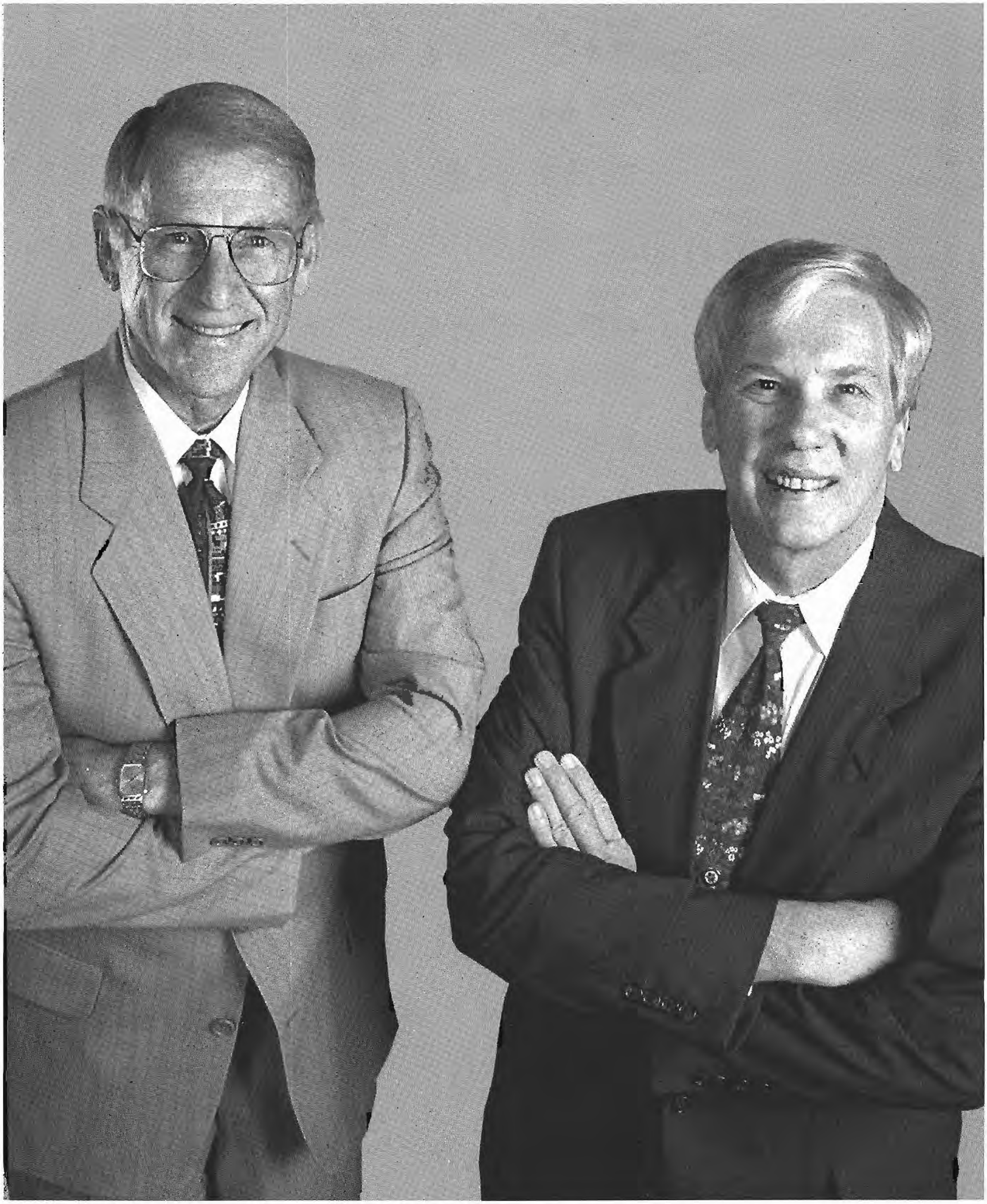
As national defense funding declined during the 1990s, a series of mergers among defense contractors ensued. In 1995 Martin Marietta merged with Lockheed Corporation, an aerospace defense firm famous for developing Stealth aircraft. As a result of this merger, the name of Sandia's contract manager became Lockheed Martin. President Al Narath and deputy director Jim Tegnelia left Sandia in August 1995 to become directors of Lockheed Martin's Energy and Environment sector with offices in Albuquerque. By this transfer, they accepted responsibility for strategic management not only of Sandia, but also of Oak Ridge, the Idaho National Engineering Laboratory, and other DOE facilities under Lockheed Martin's purview. "We've had a wonderful past, and the future is in everyone's hands," said Narath as he left Sandia. "Aim high!"

RENAISSANCE LABORATORIES

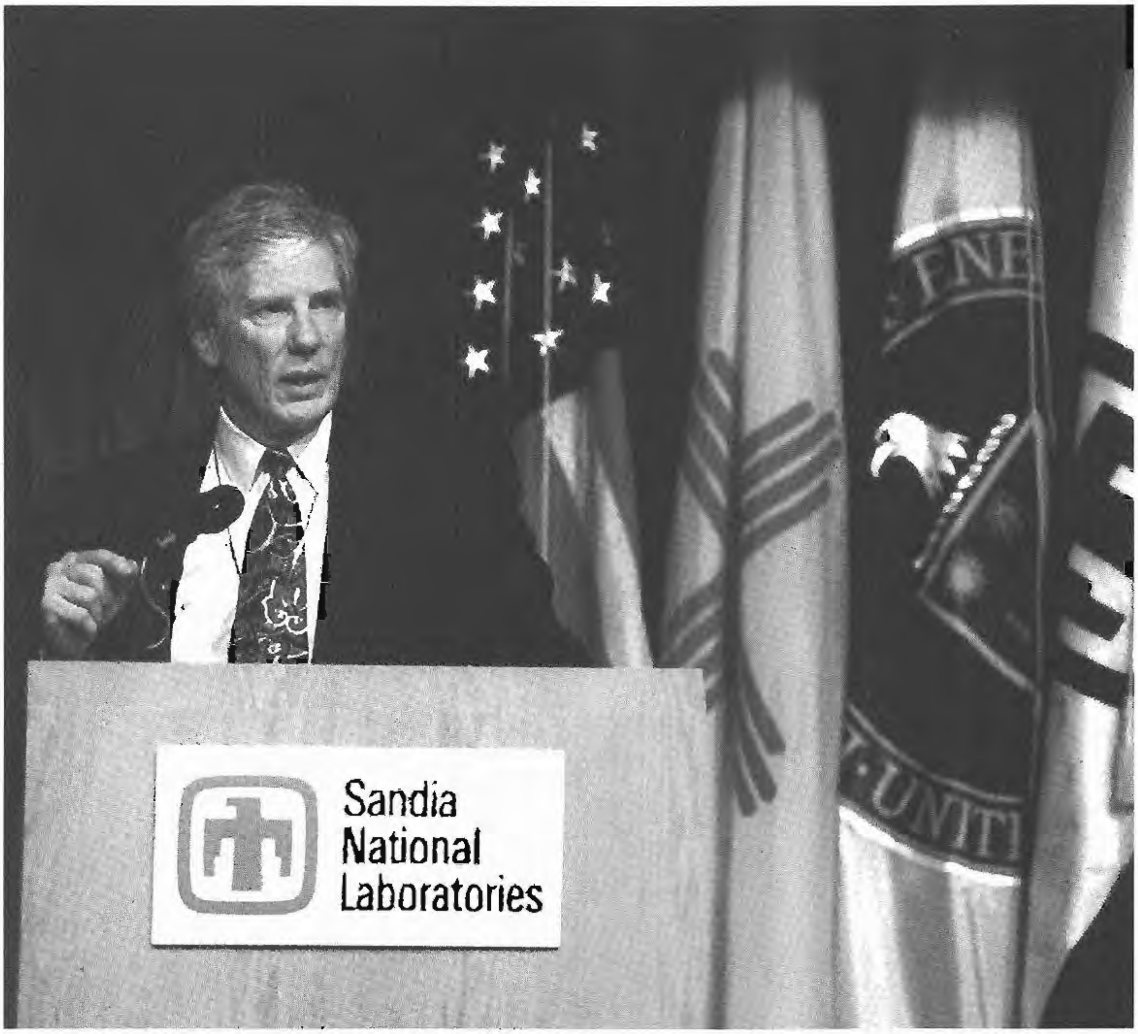
The successors to Narath and Tegnelia at Sandia in late 1995 were C. Paul Robinson and John Crawford. After earning degrees from Phillips and Kansas State University, Crawford joined Sandia in 1962, working in solid-state electronics and weapon programs until he became manager of Sandia California in 1987. Robinson earned degrees from Christian Brothers College and Florida State University and joined Los Alamos National Laboratory in 1967, working in its nuclear testing and advanced concepts groups. After directing the Los Alamos defense programs, he became senior vice president and principal scientist for Ebasco Services. He then was appointed U.S. Ambassador to lead negotiations of protocols to the Threshold Test Ban and Peaceful Nuclear Explosions treaties.

Robinson came to Sandia in 1990 as systems analysis director and subsequently became vice president for laboratory development. He perceived Sandia's internal operations as far too complex and unwieldy, yet he admitted, "When it works right, it is beautiful to behold."

In line with the recommendations of DOE and the Galvin Commission, along with the trend apparent in Congress, Robinson continued the efforts begun by Narath to streamline Sandia. He sought to renew Sandia's focus on the defense and energy-environment programs sponsored by its principal customer, the Department of



Executive Vice President John Crawford and President Paul Robinson look forward to leading Sandia into the 21st century.



Paul Robinson became Sandia's president in August 1995.

Energy. "The grand challenge," he said, "is to devise guiding principles for enlightened management that will sustain the laboratories' intellectual excellence well into the 21st century."

In a world in which the knowledge of nuclear weapons cannot be erased, avoiding nuclear conflict through deterrence and careful management of the stockpile has become a critical national priority. Sandians are proud of their contributions to nuclear deterrence across a wide field of science and technology, from parachutes to penetrators to integrated warheads. Experts have predicted that Sandia will serve as one of the nation's stockpile stewards throughout the first fifty years of the 21st century, because it will require another half-century before advancing defense technology might render nuclear weapons obsolete.

Sandia exists to serve national needs, whatever their nature. It has a hard-won reputation for marshaling its resources to meet those needs, be they defense emergencies or broader energy, environmental, and competitiveness requirements. Although future challenges will differ from those of the past, the world will secure its future through science and technology; Sandia will contribute its unique and world-class capabilities. However, the future belongs not to particular technologies like artificial intelligence and smart machines, but to Sandia's greatest resource: innovative, energetic, and dedicated people.

Notes on Sources

Due to the nature of Sandia's work, many of the sources used in writing this history are classified or limited in distribution and thus inaccessible to researchers without appropriate clearances. The following discussion is meant to serve only as a guide to further reading for those interested in knowing more about a particular topic.

Information about Sandia's technical programs has been reported in the *Sandia Science News*, *Sandia Technology*, and in the nearly 100,000 official Sandia reports — both unclassified and classified — produced by the Laboratories since its inception. We have included references to some of the relevant reports in this discussion. Copies of unclassified reports are available from the National Technical Information Service.

The names of the expert reviewers are included in the sections they reviewed. In addition, Bill Stevens reviewed the Prologue and the first five chapters in detail, while Orval Jones and Charlie Winter reviewed the entire manuscript. Including the names of the reviewers in no way implies their endorsement of the material, but serves to further explain our sources and to express our gratitude to these experts. Any inaccuracies remaining in the text are the responsibility of the author and editors.

The Sandia National Laboratories Corporate Archives in Albuquerque, NM is referred to as SNL Archives.

PROLOGUE

A great deal has been written about both the structure of the nuclear weapons complex and post-World War II engineering and science. The Atomic Energy Act and its amendments can be found in U.S. Congress, Joint Committee on Atomic Energy, *Atomic Energy Act of 1946 and Amendments* (Washington, DC: U.S. Government Printing Office, 1971). The early history of atomic weapons and the Atomic Energy Commission is thoroughly outlined in Richard G. Hewlett and Oscar Anderson, Jr., *The New World, 1939-1956*, Vol. 1 of *A History of the United States Atomic Energy Commission* (University Park: Pennsylvania State University Press, 1962); Richard Hewlett and Francis Duncan, *Atomic Shield, 1947-1952*, Vol. 2 of *A History of the United States Atomic Energy Commission* (University Park: University of Pennsylvania Press, 1969); Richard Hewlett and Jack Holl, *Atoms for Peace and War, 1953-1961*, Vol. 3 of *A History of the United States Atomic Energy Commission* (Berkeley: University of California Press, 1989). Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York: Knopf, 1977), and Bruce L. R. Smith, *American Science Policy Since WWII* (Washington, DC: The Brookings Institution, 1990) discuss the changing nature of the relationship between the federal government and the science and engineering communities. The impact of World War II and the move from war to peace are addressed in the articles contained in Robert Seidel and Paul Henriksen, eds., *The Transfer of Technology from Wartime Los Alamos to Peacetime* (Los Alamos: Los Alamos National Laboratory, 1992). Technological enthusiasm is discussed in Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970* (New York: Viking, 1989). An overview of the Department of Energy (DOE) nuclear weapons research, development, and testing program, including a summary of the division of responsibilities between DOE and the Department of Defense (DoD) can be found in Glen R. Otey, *DOE Nuclear Weapon RD&T: Objectives, Roles, and Responsibilities*, SAND89-1243 (Albuquerque: Sandia National Laboratories, 1989).

CHAPTER I: FROM Z TO A CORPORATION

A model for comparative history of government laboratories is provided by Hans Marks and Arnold Levine, *The Management of Research Institutions: A Look at Government Laboratories* (Washington, DC: National Aeronautics and Space Administration, 1984). To compare Sandia's historical evolution with other laboratories, consult Robert Crease, "The History of Brookhaven National Laboratory: Part One," *Long Island Historical Journal* 3 (Summer 1991): 167-87, and "The History of Brookhaven National Laboratory: Part Two," *Long Island Historical Journal* 4 (Spring 1992): 138-61; Leonard Greenbaum, *A Special Interest: The Atomic Energy Commission, Argonne National Laboratory, and the Midwestern Universities* (Ann Arbor: University of Michigan Press, 1971); David Hawkins, Edith Truslow, and Ralph Smith, *Project Y: The Los Alamos Story* (Los Angeles: Tomash Publishers, 1983); J. L. Heilbron and Robert Seidel, *Lawrence and His Laboratory: A History of the Lawrence Berkeley Laboratory,* Vol. 1 (Berkeley: University of California Press, 1989); Leland Johnson and Daniel Schaffer, *Oak Ridge National Laboratory: The First Fifty Years* (Knoxville: University of Tennessee Press, 1994); William Klingaman, *APL-Fifty Years of Service to the Nation* (Laurel, MD: Applied Physics Laboratory, 1993); and Lawrence Livermore National Laboratory, *Preparing for the 21st Century: 40 Years of Excellence,* UCRL-AR-108618 (Livermore, CA: Lawrence Livermore National Laboratory, 1992).

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Information about Sandia's site is found in Don Alberts and Allan Putnam, *A History of Kirtland Air Force Base, 1928-1982* (Albuquerque: Kirtland Air Force Base, 1982); and Kirtland Air Force Base, *Through the Years* (Albuquerque: Kirtland Air Force Base, 1991). See also, Ralph Baldwin, *The Deadly Fuze: The Secret Weapon of World War II* (San Rafael, CA: Presidio Press, 1980.

Sandia's formation and early history is described in Frederic Alexander, *History of Sandia Corporation Through Fiscal Year 1963* (Albuquerque: Sandia Corporation, 1963); David Lilienthal, "The Kind of Nation We Want," *Colliers,* 14 June 1952, p. 49; Kimball Prince, *Sandia Corporation: History of Formation, February-October 1949* (Albuquerque: Sandia Office of Counsel, 1960); Rowe, *Project W-47;* and Necah Furman, *Sandia National Laboratories: The Postwar Decade* (Albuquerque: University of New Mexico Press, 1990), which cites primary sources for Sandia's early history. Glenn Fowler served as subject expert for the sections pertaining to Z-Division activities.

Documents on Z-division can be found in the Los Alamos National Laboratory Archives in collections 310.1 "Z" 1/47 thru 11/48; 310.1 Z-Div.; and A-84-019, Files 7-3, 36-10, and 49-9. Correspondence in the SNL Archives relating to Sandia's formation includes letters to Frederic Alexander from Leslie R. Groves, 6 June 1961; Robert Oppenheimer, 25 May 1961; Wilbur Schaffer, Jr., 10 May 1962; James McCormack, 5 December 1961; Alvin Graves, 30 June 1961; and Lyle Seeman, 5 February 1962; and Mervin Kelly to D. P. Severance, 25 July 1961. Also consult the Sandia Corporation, *Annual Report* (classified), first issued in 1950, for pertinent years; copies are held in the SNL Archives.

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The early history of the AEC Santa Fe and Albuquerque Operations Offices is detailed in *Sandia Bulletin*, 22 June 1951, 18 January 1952, 10 October 1952, and 21 November 1952; and in the Sandia *Lab News*, 15 January 1954, 16 July 1954, 27 August 1954, 8 October 1954, and 1 July 1955. See also, Department of Energy, *Story of Albuquerque Operations*, AL pamphlet 3100-02 (Albuquerque: DOE Albuquerque Operations Office, 1978); Department of Energy, *AL Vistas* (Albuquerque: DOE Albuquerque Operations Office, 1985); and Department of Energy, *DOE THIS MONTH*, October 1995, pp. 8-11.

Early weapons are described in the series of weapon histories written primarily by Frederic Alexander; see Sandia Corporation, *History of the Mark 4 Bomb*, SC-M-67-544 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mark 5 Bomb*, SC-M-67-545 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mk 5 Warhead*, SC-M-67-546 (Albuquerque: Sandia Corporation, 1967) (classified); and *History of the Mk 6 Bomb (Including the TX/XW-13, Mk18 and TX-20)*, SC-M-67-726 (Albuquerque: Sandia Corporation, 1967) (classified). An overview of Operation Sandstone planning and organization is presented in Sandia Laboratory Group, *Sandstone Report 41: Scientific Director's Report of Atomic Weapon Tests at Eniwetok, 1948*, Annex 17, Parts II and III (Albuquerque: Sandia Laboratory, 1948). On the Korean War and the pressure to increase the nuclear stockpile, as well as discussion of several early weapon systems, see Roger M. Anders, *Forging the Atomic Shield: Excerpts from the Office Diary of Gordon E. Dean* (Chapel Hill: University of North Carolina Press, 1987). Glenn Fowler, Tom Marker, Del Olson, and Phil Owens reviewed the sections pertaining to early weapon programs, including emergency capability. Glenn Fowler also reviewed the sections on weapon effects and reliability. The Greenfruit section was reviewed by Tom Marker.

Histories of AT&T and Bell Laboratories include John Brooks, *Telephone: The First Hundred Years* (New York: Harper & Row, 1976); M. D. Fagen, ed., *A History of Engineering and Science in the Bell System: National Service in War and Peace, 1925-1975* (Murray Hill, NJ: Bell Telephone Laboratories, 1978); and Prescott Mabon, *Mission Communications: The Story of Bell Laboratories* (Murray Hill, NJ: Bell Telephone Laboratories, 1975).

CHAPTER II: THE EISENHOWER BUILDUP

Among reviews of nuclear weapon policies during the Eisenhower administration are Michael Armacost, *The Politics of Weapons Innovation: The Thor-Jupiter Controversy* (New York: Columbia University Press, 1969); Robert A. Divine, *Blowing on the Wind: The Nuclear Test Ban Debate, 1954-1960* (New York: 1978); Robert A. Divine, *The Sputnik Challenge* (New York and Oxford: Oxford University Press, 1993); Lawrence Freedman, *The Evolution of Nuclear Strategy* (New York: St. Martin's Press, 1983); Fred Kaplan, *The Wizards of Armageddon* (New York: Simon and Schuster, 1983); Richard Rhodes, *Dark Sun: The Making of the Hydrogen Bomb* (New York: Simon & Schuster, 1995); Matthew Taylor, "Toward a Nuclear Strategy: Eisenhower and the Challenge of Soviet Power, 1952-1956," Ph.D. dissertation, Rice University, 1992; and Herbert York, *Making Weapons, Talking Peace: A Physicist's Odyssey from Hiroshima to Geneva* (New York: Basic Books, Inc., 1987).

Personal accounts of Eisenhower policy and the arms race include James R. Killian, *Sputnik, Scientists, and Eisenhower: A Memoir of the First Special Assistant to the President for Science and Technology* (Cambridge: MIT Press, 1977); George B. Kistiakowsky, *A Scientist at the White House: The Private Diary of President Eisenhower's Special Assistant for Science and Technology* (Cambridge: Harvard University Press, 1976); Frank H. Shelton, *Reflections of a Nuclear Weaponeer* (Colorado Springs, CO: Shelton Enterprises, Inc., 1988); Herbert York, *Race to Oblivion: A Participant's View of the Arms Race* (New York: Simon and Schuster, 1970); and York, *Making Weapons.*

Alexander, *Sandia Corporation,* and Furman, *Sandia National Laboratories,* review Sandia's history during the 1950s. See also, Arch Napier, "Sandia Corporation: On the Frontier of Engineering," in *Sandia Corporation, Albuquerque, New Mexico,* brochure, reprinted from *Sun Trails Magazine,* 1954. Among primary sources are Sandia Corporation, *Annual Report* (classified); *Sandia Bulletin;* and *Lab News.* Also useful are speeches by George Landry, Donald Quarles, James McRae, Robert Henderson, and various staff members in Collection 76, Speeches by Sandia Management, SNL Archives.

For Sandia's early production roles, see Sandia Corporation, *A Summary of 2100,* brochure (Albuquerque: Sandia Corporation, 1951) held in the SNL Archives.

Information on some early nuclear weapons can be assembled from Don Bohrer, "8100 Directorate: The First Thirty Years," internal report (limited), 1987, Collection 69, Livermore History, SNL Archives; Sandia Corporation, *History of the Mk 7 Bomb,* SC-M-67-547 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mk 7 Warhead,* SC-M-67-548 (Albuquerque: Sandia Corporation, 1967) (classified); *History of Gun-Type Bombs and Warheads, Mks 8, 10, and 11,* SC-M-67-658 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Early Thermonuclear Weapons, Mks 14, 15, 16, 17, 24, and 29,* SC-M-67-658 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mk 25 Warhead,* SC-M-67-663 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mk 27 Weapon,* SC-M-67-664 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mk 28 Weapon,* SC-M-67-665 (Albuquerque: Sandia Corporation, 1968) (classified); *History of the Mk 30 Warhead,* SC-M-67-666 (Albuquerque: Sandia Corporation, 1967) (classified); *History of the Mk 43 Bomb,* SC-M-67-675 (Albuquerque: Sandia Corporation, 1968) (classified); and *History of the Mk 54 Weapon,* SC-M-67-686 (Albuquerque: Sandia Corporation, 1968) (classified). Phil Owens reviewed the information pertaining to emergency fusion bombs.

A short overview of weapon assembly facilities and the Pantex Plant is provided in George T. West, *United States Nuclear Warhead Assembly Facilities (1945-1990)* (Amarillo, TX: Mason & Hanger — Silas Mason Co., Inc., Pantex Plant, 1991).

On laydown bomb development, see Randy Maydew, "Some Bomb Background," *NAM News* 3 (November 1994): 5-6; Sandia Corporation, *Illustrations of Contributions from Research and Technology to Development of Nuclear Weapons Systems and Subsystems — An AEC Input to Project Hindsight,* SC-WD-66-366 (Albuquerque: Sandia Corporation, 1966), unclassified version held in the Sandia Histories Collection, SNL Archives. On the history of parachute development, see R. C. Maydew and C. W. Peterson, *Design and Testing of High-Performance Parachutes,* AGARD-AG-319 (Neuilly-sur-Seine, France: Advisory Group for Aerospace Research & Development (AGARD), 1991). For a description of aerodynamic test facilities, see R. C. Maydew, *Sandia Laboratory Aerodynamic Test Facilities,* SC-4937(M) (Albuquerque: Sandia Laboratory, 1963). Randy Maydew and Alan Pope served as expert reviewers on parachute development. Ted Church reviewed the section called "Zippers," while Jay W. Grear, Jr. and Del Olson served as subject experts for one-shot components. The discussion of the building block concept was reviewed by Del Olson and Walt Treibel.

Information on nuclear testing during the 1950s may be obtained from John Banister, *Historical Sketches of Sandia National Laboratories Nuclear Field Testing,* SAND93-7054 (Albuquerque: Sandia National Laboratories, 1994); see also, Everett Cox, "Atomic Bomb Blast Waves," *Scientific American* 188 (April 1953): 94-102.

The creation of Lawrence Livermore National Laboratory is discussed in Lawrence Livermore National Laboratory, *Preparing for the 21st Century;* and York, *Making Weapons.* On the formation of Sandia Laboratories in California, see reports in Sandia *Lab News,* 1956-58; see also, Bohrer, "8100 Directorate."

Doug Ballard reviewed the section on handling safety devices generally, while Jack Wiesen focused on quality aspects.

General histories of the Polaris project include James Baar and William Howard, *Polaris!* (New York: Harcourt, Brace and Co., 1960); and Harvey Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Government* (Cambridge: Harvard University Press, 1972).

CHAPTER III: FROM MORATORIUM TO TEST BAN TREATY

The history of nuclear testing is summarized in Roger Anders, *The United States Nuclear Weapon Testing Program: A Summary History,* DOE/ES-0005 (Washington, DC: Department of Energy, 1986); and Banister, *Historical Sketches.* See also, John Weydert, "Fast-Acting Blast Doors Protect Nuclear Experiments," *Machine Design,* 25 March 1982, pp. 84-85. For analysis of the 1958 moratorium and the eventual return to testing, see William Ogle, *An Account of the Return to Nuclear Weapons Testing by the United States after the Test Moratorium, 1958-1961* (Las Vegas: DOE Nevada Operations Office, 1985), a declassified version of this publication is available at DOE/NV Coordination and Information Center, Las Vegas, Nevada, document number NVO291. A comprehensive list of American nuclear tests is contained in Department of Energy, *United States Nuclear Tests, July 1945 through September 1992,* DOE/NV-209 (Rev. 14) (Washington, DC: U.S. Government Printing Office, 1995). Film footage of several atmospheric tests has been collected and restored in Peter Kuran, producer, *Trinity and Beyond* (Sylmar, CA: VCE, Inc., 1996). Expert review on nuclear testing was provided by Carter Broyles, Richard Eno, Clarence Mehl, and Jim Scott.

Views of AEC chairmen during the moratorium are found in Lewis Strauss, "The U.S. Atomic Energy Program, 1953-1958," *Bulletin of the Atomic Scientists* 14 (September 1958): 256-58; Glenn Seaborg, *Kennedy, Khruschev, and the Test Ban* (Berkeley: University of California Press, 1981); Glenn Seaborg, *Stemming the Tide: Arms Control in the Johnson Years* (Lexington, MA.: D. C. Heath and Co., 1987). Planning for AEC laboratories in the 1960s is discussed in U.S. Congress, Joint Committee on Atomic Energy, *The Future Role of the Atomic Energy Commission Laboratories,* 86th Cong., 2d Sess., 1960; and V. Lawrence Parsegian, "On the Role of Government Laboratories," *Bulletin of the Atomic Scientists* 22 (September 1966): 35-36.

For Sandia's general history during the 1950s, consult Furman, *Sandia National Laboratories;* the Sandia *Lab News;* Sandia Corporation, *Annual Report* (classified); and the speeches of F. G. Given, Max Howarth, James McRae, Ray Powell, and Siegmund Schwartz in Collection 76, Speeches by Sandia Management, SNL Archives. Especially useful are articles on Sandia ordnance engineering in Sandia *Lab News,* 29 November, 13 December, 27 December 1957; and 10 January, 24 January, and 7 February 1958. Descriptive as well is the 1958 recruiting film made for Sandia Corporation, *The Sandia Story* (Hollywood: Lookout Mountain, 1958), on videotape in the SNL Archives. Charles Burks and Tom Edrington provided expert review of Sandia's weapon programs for this period. Doug Ballard served as expert reviewer of the discussion of timers, while Ray Schultz reviewed the section on storage sites.

Project Sherwood is discussed in Amasa Bishop, *Project Sherwood: The U.S. Program in Controlled Fusion* (Reading, MA: Addison-Wesley Publishing Co., 1958); and Joan L. Bromberg, *Fusion: Science, Politics, and the Invention of a New Energy Source* (Cambridge: MIT Press, 1982). The section on diversification was reviewed by Howard Stump.

On Plowshare studies, see Atomic Energy Commission, *Project GNOME,* ALO Pamphlet 3100-1 (Albuquerque: DOE Albuquerque Operations Office, 1961); Banister, *Historical Sketches;* Gerald W. Johnson, "Excavation with Nuclear Explosives," *Physics Today* (November 1963): 38-44; F. Kreith and C. B. Wrenn, *Nuclear Impact — A Case Study of the Plowshare Program to Produce Natural Gas by Underground Nuclear*

Stimulation in the Rocky Mountains (Boulder, CO: Westview Press, 1976); Dan O'Neill, "Project Chariot: How Alaska Escaped Nuclear Excavation," *Bulletin of the Atomic Scientists* (December 1989): 28-37; *Proceedings of the Second Plowshare Symposium, May 13-15, 1959, San Francisco, California; Part II: Excavation,* UCRL5676 (Livermore, CA: University of California Radiation Laboratory); and Luke J. Vortman, "Ten Years of High Explosive Cratering at Sandia Laboratory," *Nuclear Applications & Technology* 7 (September 1969): 269-304. Byron Murphey, Jack Reed, Dean Thornbrough, Wendell Weart, and Luke Vortman served as subject expert reviewers for the section on Plowshare.

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The history of nuclear reactors and particle accelerators at Sandia is traced in A. Hasenkamp, *Final Hazards Summary for the Sandia Engineering Reactor Facility,* SC-4522 (Albuquerque: Sandia Corporation, 1961); Sandia National Laboratories, *Environmental Impact Assessment: Sandia Laboratories, Albuquerque, New Mexico,* EIA/MA 77-1 (Albuquerque: Sandia Laboratories, 1977); and Richard Claassen to Orval Jones, 3 September 1993, in SNL Archives. Department of Energy, *Pinellas Plant Facts,* MMSC-SP-008 (Pinellas, FL: Martin Marietta, 1992) briefly outlines this plant's history. Origins of scientific research at Sandia are discussed in Glenn Fowler to James McRae, 18 February, 1957, in SNL Archives. See also, Sandia Corporation, *Fundamental and Applied Physical Research at Sandia Laboratory,* pamphlet (Albuquerque: Sandia Corporation, 1960).

Origins of Sandia's earth-penetrator studies are reviewed in T. W. H. Caffey, "Communication with an Earth Penetrator," *Sandia Technology* (June 1976): 29-31; Norman Carlisle, "Probe Earth's Secrets," *Science & Mechanics,* January 1969; "It's Terradynamic," *Newsweek,* 25 March 1968, p. 82; "Projectiles Reveal Subsurface Secrets," *Engineering News-Record,* 21 March 1968, p. 68; and P. L. Walter and C. E. Dalton, "Terradynamics," *Sandia Technology* (May 1981): 3-10. Bill Caudle, Pat Patterson, and Alan Pope served as expert reviewers on the subject of earth penetrators.

On the Pebbles studies and subsequent development of MIRV, see Kaplan, *Wizards of Armageddon;* Ronald Tammen, *MIRV and the Arms Race: An Interpretation of Defense Strategy* (New York: Praeger Publishers, 1973); and York, *Making Weapons.* Bob Clem and Charlie Winter reviewed this section.

Papers on Sandia's carbon research for reentry heatshields include William C. Chard, et al., *Investigation of Graphite's Response to Severe Reentry,* SC-CR-70-6075 (Albuquerque: Sandia Laboratories, 1971); D. J. Rigali and L. F. Miller, *Material Test Vehicle Preflight Report for Reentry Vehicles MTV-I-1 and MTV-I-2,* SC-DR-70-340 (classified) (Albuquerque: Sandia Laboratories, 1970); H. W. Schmitt, *Preliminary Material Test Vehicle Preflight Report,* SC-DR-67-756 (classified) (Albuquerque: Sandia Laboratories, 1968); and H. M. Stoller, E. R. Frye, and D. F. McVey, *The Sandia Corporation Carbon Development Program,* SC-DR-67-574A (Albuquerque: Sandia Laboratories, 1967). This subject was reviewed by Walt Herrmann and Heinz Schmitt. Jack Wirth reviewed information pertaining to reentry vehicle hardening.

For Sandia's development of the permissive action link (PAL), consult Del Olson, "Presentation on PAL," manuscript, 1985, SNL Archives. See also, Shaun Gregory, *The Hidden Cost of Deterrence: Nuclear Weapons Accidents* (New York: Brassey's, 1990); and Peter Stein and Peter Feaver, *Assuring Control of Nuclear Weapons: The Evolution of Permissive Action Links* (Cambridge: Harvard University Press, 1987). Del Olson and Bill Stevens provided expert review of this section.

On early technology spinoffs, see Atomic Energy Commission, *The Atomic Bonus: Non-Nuclear Benefits from Nuclear Development,* pamphlet (Washington, DC: Atomic Energy Commission, 1968). Clean room development is reviewed in Larry Waller, "Clean-Room Inventor Whitfield Leaves a Spotless Legacy," *Electronics Week* (4 February 1985): 38; Willis Whitfield, *The Basic Function of a Clean Room,* SC-DC-67-2377

(Albuquerque: Sandia Laboratories, 1968); and Willis Whitfield and D. M. Garst, *Contamination Control: A State-of-the-Art Review,* SC-R-69-1154 (Albuquerque: Sandia Laboratories, 1968). Discussions of rolamite are included in "Rolamite Linkage Reduces Friction in Motion Recording Instrumentation," *Sandia Science News,* September 1972, p. 3; Sandia Laboratories, *Rolamite Facility Equipment and Capabilities,* SC-M-69-59 (Albuquerque: Sandia Laboratories, 1969); D. F. Wilkes, *Rolamite: A New Mechanical Design Concept,* SC-RR-67-656A (Albuquerque: Sandia Laboratories, 1967); and many articles in Sandia *Lab News,* beginning with the 2 October 1967 issue. Willis Whitfield reviewed the section on the clean room.

Reviews of the VELA program are found in H. M. Dumas and G. H. Mauth, "Satellite Instruments for Monitoring the Limited Test Ban Treaty," *Sandia Technology* (May 1984): 8-11; Ann Kerr, ed., *The VELA Program: A Twenty-Five Year Review of Basic Research* (Washington, DC: Defense Advanced Research Projects Agency, 1985); Ogle, *An Account;* and "Sandia is Testing Seismic Observatory for Detection of Nuclear Detonations," *Sandia Science News,* April 1966, pp. 3-4. Gary Mauth, Bill Myre, Richard Spalding, and Paul Stokes reviewed the VELA section.

The 1962 resumption of nuclear testing is reviewed in Anders, *The United States Nuclear Weapon Testing Program;* Banister, *Historical Sketches;* and Ogle, *An Account.* See also, Glenn A. Fowler, Randall C. Maydew, and William R. Borton, *Sandia Laboratories Rocket Program — A Review,* SAND76-0184 (Albuquerque: Sandia Laboratories, 1979). Glenn Fowler served as subject expert for sections pertaining to the resumption of nuclear testing.Details of President Kennedy's visit to Sandia are found in Albuquerque newspapers and Sandia *Lab News* during December 1962.

CHAPTER IV: A DIVERSIFIED LABORATORY

On national policies of the early 1960s, consult Seaborg, *Kennedy;* Jerome Wiesner, "On Science Advice to the President," *Scientific American* 260 (January 1989): 34-39; and York, *Making Weapons.* Sandia's roles in carrying out these policies may be traced through Sandia *Lab News,* and in speeches by Robert Henderson, Julius Molnar, and Siegmund Schwartz, in Collection 76, Speeches by Sandia Management, SNL Archives. See also, John Hornbeck, "Sandia," *Western Electric Engineer* 11 (April 1967): 2-3, 16. Discussion of the Limited Test Ban Treaty can be found in *Arms Control and Disarmament Agreements: Texts and Histories of the Negotiations* (Washington, DC: United States Arms Control and Disarmament Agency, 1990); and U.S. Congress, Senate, Committee on Foreign Relations, *Nuclear Test Ban Treaty Hearings, August 1963* (Washington, DC: U.S. Government Printing Office, 1963).

On Sandia's services in conducting underground tests at the Nevada Test Site (NTS), consult Banister, *Historical Sketches;* and Ogle, *An Account.* Robert Bass, Allen Church, Hugh Church, Byron Murphey, Bill Perret, Bob Stinebaugh, Dean Thornbrough, and Wendell Weart brought their considerable expertise to the review of Sandia's underground test activities.

Discussion of the SNAP program is provided in William Harwood, *Raise Heaven and Earth: The Story of Martin Marietta People and Their Pioneering Achievements* (New York: Simon & Schuster, 1993). Details of Sandia's participation are found in Sandia *Lab News* of the 1960s; Sandia Corporation, *Annual Report* (classified) for the 1960s; and "Apollo Instrument Package Heater Tested for Safety, Ruggedness," *Test Engineering,* May 1969, pp. 20-25. Subject experts for SNAP were Tom Edrington and Sam Jeffers.

Accounts of the planetary quarantine program include "Planetary Quarantine Studies Aid Apollo Lunar Sampling Project," *Sandia Science News,* March 1969, p. 4; and "Simultaneous Heat and Radiation Speeds Space Sterilization Process," *Sandia Science News,* September 1969, p. 2. Bill Stevens, Chuck Trauth, and Willis Whitfield provided subject area expertise on planetary quarantine.

Sandia's role in readiness may be traced in "AEC-DOD Agreement for the Development and Review of a National Nuclear Test Plan in Support of Limited Test Ban Treaty Safeguards," 1964, Thomas Cook Papers, SNL Archives; *Kauai Test Readiness Facility,* brochure (limited) (Washington, DC: Atomic Energy Commission, n.d.); and "Sandia's Flying Labs," *Telephony* (February 1968): 6-8. Richard Eno and Herb Filusch were the subject area experts for the readiness section.

Information on the Unmanned Seismic Observatory is contained in "Sandia is Testing Seismic Observatory for Detection of Nuclear Detonations," *Sandia Science News,* April 1966, pp. 2, 4; "Technology for Verifying Nuclear Arms Control Treaties," *Sandia Technology* (November 1984); "Unmanned Seismic Observatory Emplaced in NE Utah for Environmental Testing," *Sandia Science News,* July 1966, p. 4; "Unmanned Seismic Observatory Project Now Going into Prototype Production," *Lab News,* 5 November 1965; and "USO Units are Operating Successfully," *Lab News,* 25 August 1967.

For information on 1960s weapon systems, see Sandia Corporation, *History of the Mk 56 Warhead,* SC-M-68-48 (Albuquerque: Sandia Corporation, 1968) (classified); Sandia Corporation, *History of the Mk 59 Warhead,* SC-M-68-51 (Albuquerque: Sandia Corporation, 1968) (classified); and Sandia Corporation, *History of the TX-61 Bomb,* SC-M-710339 (Albuquerque: Sandia Corporation, 1971) (classified). For the Poseidon project, consult Sapolsky, *The Polaris System Development.* Charles Burks and Tom Edrington provided expert review of the B61 section. Edrington also reviewed the section on ballistic missiles.

On low-level aircraft testing, see Joint Task Force Two, News Releases, 65-10 (26 March 1965) and 66-19, in SNL Archives; "JTF-2 Test, May-July 1965," in Organization 3160 files, SNL Archives; Johnson, *Tonopah Test Range;* and descriptions of the tests printed in Sandia *Lab News,* 1965-1968.

The significance of Sandia's seismic sensors in Vietnam is outlined in John Bergen, *Military Communications: A Test for Technology* (Washington, DC: Center of Military History, 1986); Paul Dickson, *The Electronic Battlefield* (Bloomington: Indiana University Press, 1976); Nigel Hey, "Remote Instrumentation," *Industrial Research* (June 1970): 58-61; and Tom McConnell, "Tactical Remote Sensor Systems," *Sandia Technology* (April 1989): 33-38. Richard Beasley, Charlie Blaine, Tom Edrington, Bill Hoagland, and Tom McConnell were subject area experts for Sandia's Vietnam programs.

General discussion of nuclear weapon accidents and safety is included in Scott Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons* (Princeton, NJ: Princeton University Press, 1993); and Stanley D. Spray, *History of U.S. Nuclear Weapon Safety Assessment: The Early Years,* SAND96-1099C (Albuquerque: Sandia National Laboratories, 1996). On the Palomares accident, see Flora Lewis, *One of Our H-Bombs is Missing* (New York: McGraw-Hill, 1967); and Randy Maydew, "Recovering the Lost H-Bomb at Palomares," *NAM News* 3 (November 1994): 4-5. Del Olson, Stan Spray, and Bill Stevens reviewed the weapon safety section.

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CHAPTER VIII: AT THE THRESHOLD

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CHAPTER IX: THE COMPETITIVE EDGE

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CHAPTER X: THE AGILE LABORATORIES

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Index