Shock Wave and High Pressure Phenomena

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James R. Asay • Lalit C. Chhabildas
R. Jeffery Lawrence • Mary Ann Sweeney

Impactful Times

Memories of 60 Years of Shock Wave Research at Sandia National Laboratories

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James R. Asay, retired
Sandia National Laboratories,
Albuquerque, NM, USA

Lalit C. Chhabildas, retired
Sandia National Laboratories,
Albuquerque, NM, USA

R. Jeffery Lawrence, retired
Sandia National Laboratories,
Albuquerque, NM, USA

Mary Ann Sweeney
Sandia National Laboratories,
Albuquerque, NM, USA

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Preface

The effort to document this history of shock wave research, entitled *Impactful Times: Memories of 60 Years of Shock Wave Research at Sandia National Laboratories*, began in the early fall of 2011. James (Jim) Asay and Lalit Chhabildas had been queried by many new staff who joined Sandia in the late 1990s and early 2000s about providing a history of shock wave technology development. To make this a comprehensive document, we decided to start from the mid 1950s, when shock wave research originated at Sandia, and carry the development of the technology and Sandia's accomplishments through to the present. *Impactful Times* includes the review of experiments in hypervelocity impact and magnetic loading to study the high-pressure response of materials, advanced models and *ab initio* theories to describe that response, and state-of-the-art computations applied to a wide range of real-world problems.

The two of us had a good knowledge of the shock wave research conducted at Sandia from the 1970s through to the present because we had joined the laboratory in the early to mid 1970s. We believed, however, that it was important to involve people who had participated in the research prior to that time as well. This was done in two ways. One was to ask those directly involved in the shock wave research back to the 1950s and 1960s to provide their personal recollections. We also talked with many of the early participants, including Lynn Barker, Al Chabai, Dennis Hayes, Roy (Red) Hollenbach, Orval Jones, Charles Karnes, Don Lundergan, Darrell Munson, and Ray Reed, to get their perspective on those early times. The other way was to invite Bob Graham to coauthor the publication, since he had initiated many of the early experimental techniques in the mid 1950s and has been a leader of shock wave research at Sandia and throughout the scientific community. Bob originally agreed to do this; however, other commitments prevented his long-term involvement. Later, R. Jeffery (Jeff) Lawrence and Mary Ann Sweeney joined the effort to produce this history. Jeff's involvement with shock wave research at Sandia dates back to 1963 when he was engaged in nuclear weapon vulnerability testing as an officer at Kirtland Air Force Base. His participation therefore provided an important part of the early history. Jeff was also closely connected to many efforts to develop the original models describing dynamic material behavior and the early

computer codes for analyzing shock wave problems. A little later, Mary Ann Sweeney joined the team. As a member of the technical staff of the Pulsed Power Sciences Center at Sandia since the mid 1970s, who used Sam Thompson's computer codes in the 1970s and 1980s, and who more recently is also serving as the editor-in-chief of the annual Department of Energy (DOE) National Nuclear Security Administration (NNSA) *Stockpile Stewardship and Management Plan*, she provided knowledge of the DOE and NNSA research programs, along with technical and editing skills that not only added depth and breadth to the book but also resulted in a concise and balanced presentation.

We organized our book into two parts. Part I, "Building Shock Wave Capabilities," discusses the development of new experimental platforms at Sandia to produce precise loading conditions and novel diagnostics to probe the behavior of shocked materials, starting in the 1950s and continuing to the present. Topics also include the complementary development of theoretical and modeling activities, experimental shock wave drivers, and diagnostics development. Throughout the technical discussions, we have attempted to identify all the key players as well as the major technologies that were developed. A brief discussion of each advance is presented, along with its assessment and attributes.

To provide a more personal account of these developments, a large number of recollections are provided in Part II, "Memories of Shock Wave Research." These individual recollections present a window into the personal perspective and experience of researchers who participated in the shock wave program at Sandia. We made a strong effort to include as many people as possible. Over 80 were contacted, with around half providing their personal experiences. Each contributor was asked to summarize his or her role in shock wave research and to highlight interesting events and anecdotes that happened along the way. We purposely gave little guidance on style and format, which is why some recollections are written as a stream of consciousness while others are more technical and consist of short annotated summaries of major papers. The result is a rich and interesting mix that highlights individual personalities, personal struggles, and technical successes. The dates provided for each person represent their hiring and retirement date at Sandia; we have also made an attempt to identify the actual dates an individual participated in shock wave research. Quotations from the individual recollections are liberally sprinkled throughout the text to bring out the perspective of the research and to provide a pointer to further reading of the recollections. In some cases (e.g., Bob Graham, Walter Herrmann, Orval Jones, George Samara, and Sam Thompson), the recollections of others were used to capture the seminal contributions that individuals made to shock wave research. In summary, the technical discussions and recollections offer a unique insight into the shock wave program that covers six decades at Sandia.

A bibliography of almost 1000 references is provided for those interested in pursuing in more detail specific areas of shock wave research and technology at Sandia. The bibliography was developed by asking the contributors to the recollections to identify 20 or so of their key publications. These were used to prepare the

discussion of experimental, modeling, and computational developments that occurred over each decade. In cases where people who made major contributions during that time did not provide their recollections or could not be contacted, a literature search was done to identify their significant contributions.

We also felt that attaching faces to those who participated in the shock wave program would add interest. Each of Chapters 2 through 7, which are organized by decade, contains a section at the end called "People and Places." The photographs in this section illustrate key facilities developed during the specific decade and the individuals who participated in shock wave research. It was not always possible to find a photograph for a person corresponding to the decade in which he or she did shock wave research; however, we were able to find photographs for most people at some point in their career, typically when they had achieved a specific milepost such as a promotion or had received an award or honor. While the photographs showing specific accomplishments are not complete, they are representative of the group's achievements. All photographs have been annotated, which helps put them in perspective. The photographs and the associated captions often tell a story in themselves.

The shock wave group as a whole has had a major impact in both management and technical arenas at Sandia National Laboratories and throughout the broader scientific community. Two individuals became executive vice presidents at Sandia, and one was appointed president of the Nevada Test Site (now known as the Nevada National Security Site), an organization involved with nuclear weapon testing activities. Many others were promoted to middle management positions within Sandia. Scientific accomplishments are equally wide-ranging. Three individuals within the Sandia shock wave program were elected to the National Academy of Engineering. A great many were promoted to top levels of scientific or engineering achievement at Sandia, either as a laboratory fellow, a distinguished member of technical staff, or a senior scientist; one retired from Sandia and became a Senior Technologist, a major scientific senior executive leadership and advisory position at the Air Force Research Laboratory, a large Department of Defense organization. A large number of individuals were also appointed fellows of various scientific societies and many received top awards for technical achievement in their respective scientific or engineering organizations. Another became a high-level program administrator at NNSA. These individual achievements are too extensive to report here, but the photographs in the People and Places sections provide a small glimpse into some of them. In summary, Sandia's shock wave research program has had a significant impact not only in managing technical activities but also in scientific accomplishments as part of the national and international community.

As will become apparent in our book, two major shock wave efforts have lasted for most of Sandia's history. One focused primarily on scientific aspects of shock wave phenomena, while the other emphasized engineering applications. Three of us (Asay, Chhabildas, and Lawrence) are from the engineering side, so there is a built-in bias toward this aspect of research. However, we tried to present a balanced picture of shock wave research, especially in identifying key shock wave technologies.

Also, some contributors to the recollections were involved with the science aspects of shock wave research, while others were involved with the engineering aspects of shock wave research; this gives a balanced perspective in many cases. Although we tried to be as objective as possible, we wish to apologize for any oversights that may have occurred by not recognizing specific individuals and their research.

Albuquerque, NM, USA

James R. Asay
Lalit C. Chhabildas
R. Jeffery Lawrence
Mary Ann Sweeney

Acknowledgments

Many individuals contributed to the successful completion of this book. First and foremost, we are grateful to our families and particularly to our spouses, Patricia (Pat) Asay, Annette Chhabildas, Jane Lawrence, and Edward Ricco, who patiently supported not only our careers but strongly encouraged the preparation of this book over several years. Secondly, the book would not have been possible without the contributions from researchers involved in shock wave studies who dedicated their time to prepare detailed recollections of their Sandia careers. They provided a personal touch, which became the focus for our descriptions of the technical developments in shock compression science at Sandia over the past 60 years.

Several individuals provided personal accounts that were crucial to our investigations into the early days of shock wave research at Sandia. Interviews with C. Donald (Don) Lundergan, combined with his recollections, clarified how shock wave research was organized in the 1950s; his integration of experiment, theory, and computation ultimately set the stage for the early pioneering challenges that researchers faced in bringing shock wave technology to a high-precision science. This vision for an integrated approach to shock wave research persists to the present day. Orval E. Jones complemented that early history by providing a high-level view of how shock compression science became one of the major research thrusts at Sandia. Early perspectives were also described by several researchers who helped shape the shock wave field through their innovative efforts and resulted in major advances throughout the shock wave community, while aiding Sandia's program as well. In particular, we recognize Robert (Bob) A. Graham for his groundbreaking contributions, which include the first time-resolved stress gauge that enabled many scientific and applied research applications, the initiation of research in shock chemistry at Sandia, and the founding of the Topical Group on Shock Compression of Condensed Matter as part of the American Physical Society. This topical group and its biennial conference have become the premier organization and forum for presenting and discussing shock wave research. Without these early visionary developments, our book would not have been possible. Bob was also instrumental to the development of this book by recommending initial ideas and suggestions on how a history of shock wave technologies should be organized. In addition, Lynn

M. Barker and Roy (Red) E. Hollenbach offered a unique perspective of the early history of shock wave research at Sandia by exemplifying how their innovative efforts in gun impact technologies and groundbreaking instrumentation, such as the VISAR, enabled Sandia National Laboratories to obtain and maintain leadership in the field. Albert (Al) J. Chabai, Dennis B. Hayes, and Ray P. Reed afforded additional personal perspectives of how the shock wave programs in the 1950s led to an expansion of Sandia's role to include nuclear testing at the Nevada Test Site (now known as the Nevada National Security Site).

Many others helped to investigate the early development of shock wave research at Sandia. The Sandia corporate archivist, Myra L. O'Canna, produced invaluable information by researching *Sandia Lab News* articles and archival photos of contributors who worked in the shock wave program at Sandia over the past 60 years. Her dedicated efforts clarified several issues regarding many of the individual research efforts. Marguerite E. Hess, Diana S. Gonzales, Alice Parsons, and Robert Martinez also assisted in resolving several historical questions relating to Sandia reports and copyright issues. Two corporate historians, Alan Carr at Los Alamos National Laboratory and Rebecca Ullrich at Sandia, provided information about the early years at both national security laboratories. Rebecca's efforts were also essential in locating additional archival photos.

Several investigators helped to make the manuscript more comprehensive, including (in alphabetical order) (1) Melvin (Mel) R. Baer for a descriptive rendition on the evolution of multiphase modeling of energetic materials at Sandia and a perceptive discussion of Sandia's role to help resolve the cause of the turret explosion on board the USS Battleship Iowa; (2) Mark B. Boslough for a fascinating personal account of the events leading up to the impact of the Shoemaker-Levy-9 comet on Jupiter and Sandia's participation in interpreting Hubble Space Telescope images of the event; (3) Michael (Mike) D. Furnish for a concise perspective of subcritical experiments at the Nevada National Security Site and also for his careful and diligent efforts in resolving many technical, programmatic, and publication issues; (4) Eugene (Gene) S. Hertel for an insightful and comprehensive discussion of computer code developments at Sandia National Laboratories; (5) James (Jim) E. Kennedy for laying out the events leading to an energetic materials research program at Sandia; (6) J. Michael (Mike) McGlaun for an explanation of computational developments and a firsthand narrative of Samuel (Sam) L. Thompson's contributions to computer code development at Sandia, which underlie many of the contributions to solving national and international shock wave research problems; and (7) Bruno Morosin for a detailed description of the research program initiated on solid-state shock chemistry in the 1980s.

Several researchers from other laboratories were also extremely helpful in preparing the book, including (in alphabetical order) (1) Eric L. Christiansen of NASA, Johnson Space Center, Houston, TX, for assistance in providing information on the space debris program; (2) John R. Cogar, Corvid Technologies, Mooresville, NC, and Brian L. Kiser, Naval Surface Warfare Center, Dahlgren Division, VA, for advice and for providing a graphic illustrating the technical issues related to high-velocity engagements of weapon systems; (3) Jerry W. Forbes, senior scientist at

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Finally, we would like to acknowledge John M. Taylor for a thorough reading of the manuscript and for making concise recommendations to improve the accuracy of presentation and to clarify historical events. We also express our deep appreciation to the management and staff of Sandia National Laboratories, particularly in the Pulsed Power Sciences Center, for providing support and exhibiting strong interest in the completion of this book.

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