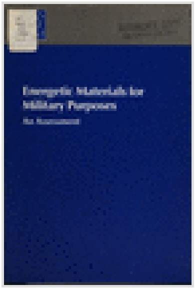

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ENERGETIC MATERIALS FOR MILITARY PURPOSES: AN ASSESSMENT

A Report Prepared by the
Committee on Energetic Materials Science and Technology
Board on Army Science and Technology
Commission on Engineering and Technical Systems
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

This report responds to a request from the Department of the Army to the National Research Council for an assessment of energetic materials and related technologies. The Assistant Secretary of the Army (Research, Development and Acquisition) requested an assessment of the posture of the U.S. Army energetic mate- rials research and development (R&D) program relative to the state of the art. In this context, the term "energetic materials" means explosives, propellants, and pyrotechnics, as well as incendiary substances and fuel/air explosives and, as appropriate, the modes of applying such material in weapon systems.

In addition, the Army requested an evaluation of whether the level of program activities is appropriate in view of an alarming evaluation of munitions program activities in the Soviet Union. Accordingly, the Army stressed the importance of a study of both U.S. and Soviet energetic materials science and technology and a consideration of the implications for military application in conventional nonnuclear munitions, including related factors such as ballistics technology, vulnerability, safety, and availability.

In response to the Army's request, the Board on Army Science and Technology established a Planning Panel chaired by Dr. William G. McMillan. Other Panel members were Dr. Arden Bement, Dr. Walter LaBerge, Mr. Charles H. McKinley, and Dr. M. Frederick Hawthorne. This Panel met on September 16, 1984, to receive briefings from the Army about its interest in the energetic materials situation.

Before proceeding with the National Research Council study, the Planning Panel felt that it would be helpful if the Army conducted two studies that would provide important information for the Board's effort. The first would be a survey of relevant technical/military problems. In this study, the Army would clearly identify the outstanding technical/military problems that new high-energy materials having differing properties not now available might ameliorate or solve. Specifically, the survey should include such topics as manufacturing, packaging, logistics, field handling, delivery to target, and target effects. The Army conducted a survey along these lines and gave the resulting report, entitled Survey of U.S. Energetic Materials Technology (1984), to the Committee.

The second study would be a technical/military operations analysis. In this study, the Army would determine areas in which the greatest gains and improvements were likely to be found; identify high-leverage items; and provide direction on what program activities could make significant improvements. The study would address delivery means, guidance, warheads, fuses, and weapons effects. The analysis would highlight the relative potential gains in target-effectiveness of various options and would simultaneously consider the technical/ military aspects beyond the mere weapons effects, for example, developing low-cost production methods for precision-guided munitions. The Army did not conduct this study.

On the basis of discussions with the Planning Panel and the Board on Army Science and Technology, the National Research Council constituted a Committee under the Board's auspices to undertake the study proposed by the Planning Panel. The Committee comprised 10 members who have worked in the field of energetic materials and their use in practical devices. The backgrounds of the members include basic science, applied science, engineering development, and practical application in weapon systems. Several are trained in chemistry or chemical engineering, several in physics or applied physics, and several in engineering (see Appendix A for professional biographies). Although the qualifications of the Committee as a whole were well matched to the tasks set before it, the amount of its members' volunteer time was necessarily limited. As a result, it was not feasible to delve deeply into many of the particular weapon systems or into particular scientific research activities. Nor did the Committee believe that it was desirable to do so. The tasks before the Committee did not call for the detailed definition of particular R&D activities to be pursued. Instead, they called for a broader assessment of R&D programs and an identification of promising R&D areas and of opportunities for improvements. Thus, although the Committee reviewed a great deal of technical and programmatic information, and investigated some subjects in-depth, it distilled that information into the general findings and conclusions that serve as the basis for its recommendations.

In making its assessment, the Committee relied on information from four sources: (1) Committee discussion sharing the expertise of its members; (2) literature reviews (see References and bibliography section); (3) presentations by spokesmen for various Department of Defense laboratories and agencies, by intelligence agencies, and by other qualified organizations--government and nongovernment; and (4) site visits by the Committee or, in some cases, by subcommittees to important government installations, where officials showed and explained their work.

After each presentation, the Committee asked the spokesmen for copies of relevant materials. The entire collection is far too bulky for reprinting in this report, but these materials are available for inspection upon request to the Executive Director of the Board on Army Science and Technology.

The Committee first met on November 27-28, 1984, in Washington, D.C., to receive briefings from the Army on the threat and status of R&D activities at the relevant Army laboratories in the areas of energetic materials and production capabilities. The Committee's second meeting was held on January 23-25, 1985, at Stanford Research Institute International, Menlo Park, California, and at Lawrence Livermore National Laboratory, Livermore, California, in order to receive briefings from invited Army contractors on their energetic materials research and to hear from Department of Energy researchers who are involved in energetic materials research as a result of their work on nuclear weapons.

The Committee met again on March 4-5, 1985, in Washington, D.C., to receive briefings from the Army on armor/anti-armor technology as well as to meet with representatives from the other armed services and the Office of the Secretary of Defense in order to obtain an understanding of research and development activities in the government outside the Army. The Committee was unable to arrange a briefing on the military threat from the Central Intelligence Agency at this time. After these two days of briefings, the Committee decided to make an unannounced visit on March 6, 1985, to Picatinny Arsenal, U.S. Army Material Command, Dover, New Jersey, for a tour of the facility and discussions with the management and technical staffs on the energetic materials R&D work under way and projected for the Arsenal.

On March 21, 1985, a subcommittee revisited Picatinny Arsenal in order to obtain information on modifications of explosive-formed projectiles and warheads, and on March 22, 1985, visited Ballistic Research Laboratory for information on warhead/target assessment methodologies, particularly the influence of threat definition. On the same day, another subcommittee visited the Missile Command, Huntsville, Alabama, for a tour of facilities and briefings on current and projected activities, especially in the area of propellants. On April 16, 1985, another subcommittee visited the Radford Army Ammunition Plant for a tour and a briefing on production R&D activities in the Army system as well as for a review of the Army's current production capabilities.

The Committee met again in Washington, D.C., on April 17-19, 1985, for an update from the Foreign Science and Technology Center and for question-and-answer sessions with Dr. Robert Eichelberger, Director, Ballistics Research Laboratory, and Dr. Victor Lindner, Associate Director for Systems Development and Engineering, U.S. Army Armament Research and Development Center, Dover, New Jersey. On May 29-31, 1985, the Committee met at Rocketdyne, Canoga Park, California, to discuss its findings, conclusions, and recommendations and to start writing the final report.

In conducting its study, the Committee received advice and assistance from many individuals representing various Army units, government agencies, and private organizations. The Committee regrets that it can not thank them all personally, but it does extend its thanks to all those who generously gave us their time and assistance in this important task.

During the Committee's year-long study, its meetings with Army representatives were mutually informative. As a result, while the Committee prepared its report on the basis of information made available during its study, the Army undertook a number of reforms in response to the Committee's concerns. Thus, by responding constructively to the Committee's study, the Army has in some ways outpaced the Committee's report. Thus, the Committee welcomes those reforms that the Army has undertaken, and encourages it to initiate those that remain.

The Committee also wishes to thank Dennis F. Miller, Executive Director of the Board on Army Science and Technology, for his guidance in organizing and coordinating the study and for his assistance and perspective in the preparation of this report. Thanks also to Dr. Michael L. Hays, President of Editorial Consultants, Inc., for his editorial services. Finally, the Committee thanks Helen Johnson, Julia Torrence, Carlita Perry, and Cheryl Winter for their administrative support throughout this study. Without their efforts and long hours, this report could not have been completed.

M. FREDERICK HAWTHORNE, Chairman
Committee on Energetic Materials
Science and Technology

EXECUTIVE SUMMARY

INTRODUCTION

This report responds to a request from the Assistant Secretary of the Army (Research, Development and Acquisition) to the National Research Council for assessments of energetic materials and related technologies and of the appropriate level of program activities in this area. In this context, the term "energetic materials" means explosives, propellants, and pyrotechnics, as well as incendiary substances and fuel/air explosives and, as appropriate, the modes of applying such materials in weapon systems.

Two specific incentives prompted the request for this study. The first was a report entitled Soviet Fast Reaction Chemistry Research (1982), by the Central Intelligence Agency's Foreign Technology Assessment Center, and briefings related to it. Both the report and the briefings were directed by Dr. Peter Rentzepis of Bell Laboratories. The second was the appearance of new, special armors--especially reactive armor--on Soviet tanks, which make them less vulnerable to anti-tank munitions.

In response to these concerns, the National Research Council, adopting a recommendation of a Planning Panel, formed a Committee under the auspices of the Board on Army Science and Technology. The Committee's assessment of energetic materials research and development (R&D) in itself and in relation to the U.S. program addressed two separate but related Soviet challenges. The first challenge is posed by the Soviet energetic materials R&D program, which threatens to provide the Soviet arsenal with an array of advanced munitions. The second challenge is the special threat of Soviet armor. The Committee believes that this threat can be directly addressed by improved energetic materials and improved ways of using existing energetic materials, as well as improved munitions resulting from a vigorous energetic materials R&D program.

In addition, the United States has imposed a challenge on itself: the development and production of safer and less sensitive explosives and propellants in order to enable less vulnerable storage, particularly on ships and at airfields.

In making its assessment, the Committee relied on information from four sources: (1) Committee discussion sharing the expertise of its members; (2) literature reviews; (3) presentations by spokesmen for various Department of Defense (DOD) laboratories and agencies, by intelligence agencies, and by other qualified organizations--government and nongovernment; and (4) site visits by the Committee or, in some cases, by subcommittees to important government installations.

However, for several reasons, the information available to the Committee was not always complete or entirely reliable. It is probably impossible to develop a comprehensive, well-documented critique of the energetic materials programs and capabilities of closed societies like the Soviet Union and the People's Republic of China (PRC). In addition, there is no central clearinghouse in energetic materials R&D in the United States, Department of Defense (DOD), or, during this study, the Department of the Army.

- Conclusion: DOD needs a central clearinghouse of technical and management information on all DOD and DOD-related programs in energetic materials.
- Recommendation: Such a clearinghouse should be established under the auspices of the Undersecretary of Defense for Research and Engineering or one of the services designated as the executive agent.

ASSESSMENT OF SOVIET ENERGETIC MATERIALS R&D PROGRAM

The Rentzepis report (Central Intelligence Agency, 1982), which is based on a survey of the open literature, is unable to provide a complete or reliable account and assessment of the Soviet energetic materials research and development program. The Rentzepis briefing, based on very limited additional intelligence, gave the alarming impression that the Soviet energetic materials R&D program, is in some important ways, not only bigger, but also better--indeed, better in part simply because it is bigger--than the U.S. program.

- Conclusion: The Soviet commitment of larger numbers of people does not necessarily confer commensurate benefits as measured in terms of scientific productivity.
- Recommendation: The United States should develop better sources of information on foreign energetic materials R&D.

In the areas of commodity and phenomenology research, the Soviets have made a sizable investment in tetramethylene tetranitramine (HMX) and trimethylene trinitramine (RDX), the performance of which they apparently believe will not be surpassed in practice in the foreseeable future.

- Conclusion: This investment in commodities more powerful and more sensitive than energetic materials in widespread use in the United States indicates that Soviet and other Warsaw Pact forces choose to sacrifice neither performance nor numerical superiority in order to obtain increased safety or decreased vulnerability.

However, the Soviet R&D efforts are hampered by deficiencies in advanced instrumentation and computers, although these deficiencies are rapidly being remedied.

- Recommendation: The United States should maintain, monitor, and enforce stringent expert control of such technologies, but not the underlying basic sciences, which continue to be the focus of international meetings, journal publications, and other means of scientific exchanges.

THREAT OF SOVIET ARMOR

The infantry needs a more effective anti-tank weapon.

- Conclusion: Partial kills such as turret or tread kills may serve in many cases as a first step in neutralizing the mobility and thus impairing the lethality of tanks. Further, the U.S. ability to respond quickly to future armor threats will require the United States to find short-term solutions by using new weapon systems based on known materials such as HMX in improved formulations and on better production and loading technologies.

While mines will continue to be useful deterrents against tanks, the challenge in developing improved mines is posed, not by insufficiently energetic materials, but by technologies to defeat tank countermeasures intended to predetonate or disarm mines.

ASSESSMENT OF THE U.S. R&D PROGRAM

Perhaps two of the most distinctive characteristics of the U.S. program are its fragmentation and lack of coordination. Because of programmatic and funding arrangements whereby energetic materials R&D activities are part of and supported by larger munition- and propellant-oriented programs, the Army R&D program is also fragmented and uncoordinated. In addition, Army facilities are unable to support some important energetic materials R&D activities because the staffs and the facilities are aging and not being reinvigorated with promising young researchers or with more modern equipment.

- Conclusion: The Army technology base has been seriously eroded during the last decade or so, and the Army has become, but must not remain, increasingly dependent on the Department of Energy National Laboratories and the Navy for much of its technology base.
- Recommendation: The Army should take steps to upgrade viable existing research facilities, consolidate programs, coordinate activities, and integrate staff, not only to prevent further erosion of the technology base, but also to enhance that base in order to meet the needs for technological developments required by the threat. If the Army is no longer able to discharge its responsibilities for certain energetic materials R&D activities, those responsibilities should be located where they can be fully and effectively discharged.

The Army does little or no basic research as basic research is conceived of by research scientists. Research at the 6.1 level is targeted research aimed to achieve specific objectives. Although such research is undeniably important, it greatly reduces the possibilities of discovering new approaches to more effective energetic materials, or better or more economical ways of formulating, producing, and loading them. Targeted research addresses today's problems; basic research addresses tomorrow's.

- Recommendation: The Army should ensure that its energetic materials R&D program provide for basic scientific research, clearly distinguish it from targeted research, but fund both under the 6.1 funding category.

The Committee believes that the United States must have a capability for R&D on major and high-risk scientific problems and issues in the energetic materials area.

- Recommendation: In lieu of a comparable DOD capability, the Army should establish a dedicated research institute to conduct basic research. Such an institute should undertake long-term, basic research; operate free of day-to-day pressures to do short-term, targeted research; and function like a government-owned/contractor-operated national laboratory to supplement its existing research laboratories. Accordingly, it should be tasked to find more lethal, more potent, safer, and more economical energetic materials that can meet the requirements of the military services decades from now, although it could support on-going targeted research on a consulting basis.

ENERGETIC MATERIALS R&D PROGRAM

An effective energetic materials R&D program addresses itself to the synthesis, characterization, formulation, production, and loading of energetic materials. The research aspect of this program focuses both on commodities--that is, compounds and formulations with desirable characteristics--and on phenomenology--that is, the underlying reasons for the behavior of those commodities.

In the past decade or so, excessive attention has been given to synthesizing theoretically attractive, but highly improbable energetic materials, like octanitrocubane (ONC) the eventual synthesis of which may be doubtful. However, there is very little chance that chemists anywhere in the world will discover a completely new and unexpected class of energetic compounds. Indeed, the likelihood of discovering energetic compounds that increase potency very remarkably is extremely remote. It is more reasonable to expect the effectiveness of new energetic materials to be enhanced by 10 to 20 percent at most, goals that can be achieved by making higher-density compounds with an increased sensitivity.

- Conclusion: The Army's energetic materials R&D program needs a diversified basic research portfolio in both commodity and phenomenology research.
- Recommendation: This portfolio should deemphasize research in unlikely compounds like ONC in favor of the more realizable gains to be made by better formulations and better engineering of phenomena associated with initiation, combustion, and detonation-to-deflagration processes. Even so, the Army should direct and maintain a small but creative research effort to study high-risk but potentially high-payoff compounds.
- Conclusion: The Army needs to adopt a systems approach to energetic materials R&D, in which all phases in the effort are integrated to achieve maximum operational effectiveness in deployed weapons systems. For example, it is unwise to commit large amounts of resources to synthesizing compounds that will probably be too sensitive to be produced, loaded, and deployed in the field.
- Recommendation: The Army should support R&D that will make possible a variety of energetic materials or formulations tailored to specific requirements of particular munitions.

HMX appears to be the energetic material of choice for many military applications over the next several decades. However, the United States does not have in place an optimized HMX process capable of large-scale production at a reasonable cost at this time. The Committee understands that some progress has been made in finding a practical, economical method to produce HMX.

- **Recommendation:** This method should be vigorously pursued because no better energetic material appears to be in the offing. Moreover, the United States should not dismantle, but rather should maintain its small facility for producing decaborane, the precursor for carboranes and $B_{10}H_{10}^{-2}$ salts, and restore it to operation, for the existing facility is the only source of decaborane in the free world.

REFERENCES AND BIBLIOGRAPHY

Akst, I. B. 1982. Nonideal Explosives Research: Intermoleculars, Eutectics, and EAX. Idos Corporation Final Report AFATL-TR-82-79. November.

Akst, I. B., and J. Hershkowitz. 1976. Explosives Performance Modification by Consolidification of Ammonium Nitrate with Fuels. Picatinny Arsenal Technical Report PA-TR-4987. Dover, New Jersey: Picatinny Arsenal. October.

Apin, Y. 1963. Flow of a reaction in a detonation wave of a mixed explosive. Journal of Applied Mechanics and Technical Physics 5.

Armed Forces Journal International. 1983. Washington, D.C.: Army and Navy Journal, Inc. December.

Army Armor Center and School, Army Infantry Center and School. 1975. Basis for Assessing the Vulnerability of Armored Vehicles. Coordination Draft. USA, BRL, USAMSAA.

Backofen, J. E., Jr. 1980. Shaped charges vs. armor. Armor Magazine, Part 1 (July/August), Part 2 (September/October).

Beauregard, R. L. 1985. Navy Explosives Technology. Briefing given by R. L. Beauregard, Naval Sea Systems Command, Washington, D.C.

Benziger, T. M., and R. K. Rohever. 1967. Pilot Plant Production of Triaminotrinitrobenzene (TATB). 1967. Report LA-363. Los Alamos, New Mexico: Los Alamos Scientific Laboratory. January.

Benziger, T. M. 1972. X-0242: A High-Energy Plastic-Bonded Explosive. Los Alamos Scientific Laboratory Report LA-4872-MS. Los Alamos, New Mexico: Los Alamos Scientific Laboratory. February.

Benziger, T. M., R. K. Rohever, and J. J. Urizar. 1973. X-0219: A Heat-Resistant Insensitive Explosive. Report LA-5338-MS. Los Alamos New Mexico: Los Alamos Scientific Laboratory.

Bjarnholt, G. 1976. Explosive expansion works in underwater detonations. P. 540 in Proceedings of the Sixth Symposium (International) on Detonation, Coronado, California,

Boyars, C., J. R. Holden, and A. L. Bertram. 1973. MINOL IV: A New Explosive Composition Containing Ammonium Nitrate-Potassium Nitrate Solid Solution, Part 1, Naval Ordnance Laboratory Report NOLTR 73-49. March.

Cady, H. H. 1981. The ammonium nitrate-potassium nitrate system. Propellants and Explosives 6:49-54.

Cady, H. H., and K.-Y. Lee. 1983. Development of New Ammonium Nitrate Composite Explosives. Report AFATL-TR-83-54. Eglin AFB, Florida: Air Force Armament Laboratory. June.

Caveny, L. H., and A. Matuszko. 1985. AF Basic Research on Energetic Materials. Presentation made to the Committee on Energetic Materials Science and Technology, March 5, 1985.

Central Intelligence Agency, Foreign Technology Center. 1982. Soviet Fast Reaction Chemistry Research.

Chan, M. L., J. T. Bryant, and A. C. Walku. 1985. High energy propellant research for insensitive munitions. P. 147 in JANNAF Propulsion Meeting. Vol. III. San Diego, California, April 9-12, 1985.

Coburn, M. D., B. W. Harris, K.-Y. Lee, M. M. Stinecipher, and H. H. Hayden. 1985. Explosives Synthesis at Los Alamos. LANL Report LAUR-85-711. Los Alamos, New Mexico: Los Alamos National Laboratory. To be published in Industrial and

Engineering Chemistry Product Research and Development, March 1986.

Cochran, S. G., et al. 1983. Modeling Particle Size and Initial Temperature Effects on Shock Initiation of TATB-Based Explosives. Topical Conference on Shock Waves in Condensed Matter, Sante Fe, New Mexico.

Coffenberry, J., et al. 1985. Shaped charge performance against selected targets. Physics International (January 24).

Cotterman, B. W., and R. D. French. 1985. Trends in armor materials development. Army Research, Development and Acquisition Magazine (March-April).

Deneuville, P., C. Gaudin, Y. de Longueville, and J. Mala. 1981. Comparison of TATB and DINGU explosive properties. Pp. 540-547 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland, June 1981.

Department of Defense. 1982. Explosives Hazard Classification Procedures. TB 700-2.

Department of Defense. 1984a. Ammunition and Explosives Safety Standards. DOD 6055.9.

Department of Defense. 1985. Soviet Military Power. Superintendent of Documents. Washington, D.C: U.S. Government Printing Office,

dePuy, W. E. 1985. The Light Infantry: Indispensable Element of a Balanced Force. U.S. Department of the Army. June.

deRosset, W. 1985. Current and Anticipated U.S.-Soviet Concepts and Capabilities. Briefing given by W. deRosset, Ballistics Research Laboratory, March 4, 1985. Aberdeen Proving Ground, Edgewood, Maryland.

Dick, C. J. 1983. Soviet operational manoever groups, a closer look. International Defense Review (June).

Ding, J. 1981a. Striving for the development of explosion science and technology. Explosion and Shock Waves 1:2.

Ding, J. 1981b. A short survey of detonation research in china. P. 795 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland, June 1981.

Dinger, D. B., et al. 1984. Soviet Efforts in Energetic Materials. Briefing given by D. B. Dinger. Foreign Science and Technology Center, Charlottes-ville, Virginia.

Donnelly, C. N. 1982. The soviet operational manoever group: A new challenge for NATO. International Defense Review 1177-86 (September). (Reprinted in Military Review 43-60 [March 1983].)

Dremin, A. N., et al. 1981. On Decomposition Reaction Kinetics in Shock Wave Front. P. 798 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland, June 1981.

Drimmer, B. E. 1983. Navy Bank of Explosives Data (NAVBED). VSE Corporation Report NSWC MP 83-230:1:2:3:4. June.

Eichelberger, R. J. 1984. Munitions Survivability Program. Briefing given by R. J. Eichelberger, Ballistics Research Laboratory, November 27, 1984. Aberdeen Proving Ground, Edgewood, Maryland.

Eichelberger, R. J. 1985. Discussion with Committee on Energetic Materials Science and Technology. Ballistics Research Laboratory, April 18, 1985. Aberdeen Proving Ground, Edgewood, Maryland.

Egghart, H. C. 1985. Explosives Detection. Briefing given by H. C. Egghart, Belvoir R&D Center, March 4, 1985. Fort Belvoir, Virginia.

Engel, W. 1982. Procedure for the Preparation of Crystalline Nitroguanidine (NQ) of High Power Density. German Patent DE 2756335 C2. June.

Eremenko, L. T., et al. 1977. Relationship Between the Relative Detonation Impulse and Chemical Composition of an Explosive. Odessa, USSR.

Eremenko, L. T., et al. 1984. Synthesis and structure of 1,1,1,3,3, 5,5,5-octanitropentane. Journal of the American Chemical Society 709.

Erickson, L. M., et al. 1981. The electromagnetic velocity gauge: use of multiple gauges, time response and flow perturbations. P. 1062 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland. June 1981.

Falcon Research and Development Company. 1977. Technical Feasibility Study of a New Optical Active Countermeasure Concept (U). R&D Report 3270-97/BUF-12. March.

Ferrentino, G. 1985. Electromagnetic Propulsion. Briefing given by G. Ferrentino, LCWSL, March 5, 1985. Dover, New Jersey.

Finger, M., et al. 1970. Metal acceleration by composite explosives. Proceedings of the Fifth Symposium (International) on Detonation, Pasadena, California.

Finger, M., et al. 1976a. Characterization of commercial composite explosives. In Proceedings of the Sixth Symposium (International) on Detonation, Coronado, California.

Finger, M, et al. 1976b. The effect of elemental composition on the detonation behavior of explosives. In Proceedings of the Sixth Symposium (International) on Detonation, Coronado, California.

First Light on the Israeli Active Armor for MBT's, Military Technology. 1983. Bonn, Federal Republic of Germany: Monch Publishing Group. October.

Flaugh, H. L. 1975. Properties of X-0280 and X-0281. LANL Report LA 5981-MS. Los Alamos, New Mexico: Los Alamos National Laboratory June.

Frey, R. B. 1985. Reactive Armor Concepts. Aberdeen Proving Ground, Maryland: Ballistics Research Laboratory.

Glushak, B. L., et al. 1984. Initiation of solid heterogeneous explosives by shock waves. The Physics of Combustion and Explosion 20:77.

Goldstein, S., et al. 1981. Aguarium tests on aluminized ANFO. P. 1016 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland. June.

Gray, J. C., W. W. Thompson, and J. E. Flanagan. 1985. P. 535 in JANNAF Propulsion Meeting. Vol. III. San Diego, California, April 9-12, 1985.

Gu, Y., et al. 1985. The detonation reaction of the heterogeneous composite explosives. In Proceedings of the Eighth Symposium (International) on Detonation, Albuquerque, New Mexico.

Hanne, W. G. 1983. Air land battle, doctrine not dogma. USA International Defense Review 1035(August):1040.

Hardison, D. C., et al. 1979. Review of Army Analysis. Volumes I and II. April.

Held, M. 1974. Inventor: British Patent No. 1581125.

Held, M. 1983. Protective Arrangement Against Projectiles, Particularly Hollow Charge Projectiles. U.S. Patent No. 4 368 660. Federal Republic of Germany: Messerschmitt-Bolkow-Blohm.

Hershkowitz, J., and J. Rigdon. 1974. Evaluation of a Modified Cylinder Test of Metal Acceleration by Nonideal Explosives Containing Ammonium Nitrate. Technical Report 4611. Dover, New Jersey: Picatinny Arsenal.

Hershkowitz, et al. 1976. Improvement of performance of composite explosives containing ammonium, nitrate by physical synthesis. P. 439 in Proceedings of the Sixth Symposium (International) on Detonation, Coronado, California.

Hill, M. E., and J. G. Guimont. 1979. Final Report Under ONR Contract NR 093-056. Menlo Park, California: SRI International.

Hoenig, S. A. 1985. Letter to the Editor. National Defense, Journal of the American Defense Preparedness Association (July/August):12.

Humphrey, J. R. 1977. LX-14: A New High Energy Plastic Bonded Explosive. Report UCRL-52350. Livermore, California: Lawerence Livermore National Laboratory. November.

Immirizi, A., and B. Perini. 1977. Prediction of Density in Organic Crystals. Acta Crystallogr., Sect. A 33:216-218.

International Defense Review. 1978. Soviet Special Armor Capabilities Worry NATO. 1373(September).

International Defense Review. 1983. Geneva, Switzerland: Interavia, S.A. 16:11/83.

Jacoby, J., and H. Sheinfeld. 1985. Update on Soviet Efforts in Energetic Materials. Charlottesville, Virginia: Foreign Science and Technology Center.

Jane's Defense Weekly. 1985. Soviet MBT's with Applique Armour. (July 2):4.

Jianshi, Z., et al. 1983. Artificial viscosity and rate of reaction in numerical modeling of steady detonation. Explosions and Shock Waves 1:21.

Joint Technical Coordinating Group for Munitions Effectiveness (Air-to-Surface). 1975. Reactive Incendiary Munitions Effectiveness Methodology (U). 61 JTCG/ME-75-3. January.

Kamlet, J. J., and S. J. Jacobs. 1968. Chemistry of detonations. I. A. simple method of calculating detonation properties of C-H-N-O explosives. J. Chem. Phys. 48:23.

Kang, X., et al. 1981. Aquarium test: A method for determination of the detonation pressure with small quantity of explosive. Explosions and Shock Waves 2:89.

Kennedy, D. R. 1985. The Infantryman vs. the MBT. National Defense, Part I (March); Part II (April).

Kennedy, J. E. 1970. Gurney Energy of Explosives: Estimation of the Velocity and Impulse Imparted to Driven Metal. Report SC-RR-70-790. Albuquerque, New Mexico: Sandia National Laboratories. December.

Khasainov, B. A., et al. 1981. Two-phase visco-plastic model of shock initiation of detonation in high denisity pressed explosives. P. 435 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland, June 1981.

Kofman, T. P., M. S. Pevzner, L. N. Zhukova, T. A. Kravchenko, and G. M. Frolova. 1980. Methylation of 3-nitro-1,2,4-triazol-5 one. Zhurnal Organicheskoi Khimii 16:2.

Kopcsak, G. 1985. The Office of Munitions Function and Program. Briefing given by George Kopcsak, Office of Munitions, OVSDRE(TWP), March 5, 1985.

Kovalev, Y. M. 1984. Equation of state and temperature of shock compression of crystalline explosives. The Physics of Combustion and Explosion 20:102.

Kury, J. W., et al. 1965. Metal acceleration by chemical explosives. P. 1 in Proceedings of the Fourth Symposium (International) on Detonation, White Oak, Maryland.

Lannon, J. 1985. Gun Propellant Overview. Briefing by Joseph Lannon, USA Armament Research and Development Center, April 19, 1985. Dover, New Jersey.

Lawrence Livermore National Laboratory. 1981. LLNL Explosives Handbook. Properties of Chemical Explosives and Simulants. UCRL-52997. Livermore, California: Lawrence Livermore National Laboratory. March.

Lee, E., and L. Greene. 1985. Sensitivity and Vulnerability of Energetic Materials. Briefing by Edward Lee and Leroy Greene, January 25, 1985.

Lee, J. 1985. Gaseous Detonations. Briefing by John Lee, McGill University, January 24, 1985.

Lee, K.-Y. 1985. Development of New Ammonium Nitrate Composite Explosives. Final Report, October 1982-January 1984. Report LA-10276, UC-45. Los Alamos, New Mexico: Los Alamos National Laboratory. March.

Lee, K.-Y., and M. D. Coburn. 1983. Binary eutectics formed between ammonium nitrate and amine salts of 5-nitrotetrazole 1 preparation and initial characterization. Journal of Energetic Material 1(August):1.

Lindner, V. 1985. Energetic Materials Technology, An Overview. Briefing given by Victor Lindner, USA Army Research and Development Center, April 19, 1985. Dover, New Jersey.

Linxiang, S., et al. 1982. Numerical simulation of shock initiation of heterogeneous condensed explosives. Explosions and Shock Waves 2:12.

Mader, C. L. 1979. Numerical Modelling of Detonations. Berkeley, California: University of California Press.

Makhov, M. N., et al. 1981. Calculation of chemical composition of detonation products. Polish Journal of Chemistry 55:1381.

Malin, M. E., A. W. Campbell, and C. W. Mautz. 1957. Particle-size effects in explosives at finite and infinite diameters. Journal of Applied Physics 28:63.

McGuire, R. R., et al. 1981. Detonation Chemistry: An investigation of fluorine as an oxidizing moiety in explosives. P. 940 in Proceedings of the Seventh Symposium (International) on Detonation, Annapolis, Maryland.

Menz, F. L. 1974. The Navy's Injection-Molded Explosive, PBXC-303(I), DEA-AF-F/G-73004. Technical Meeting on the Physics of Explosives at Naval Ordnance Laboratory. Eglin AFB, Florida: Arm Force Armament Laboratory. April.

Menz, F. L., and E. W. Anderson. In preparation. PBX's in Large Navy Munitions Program. NSWC TR 80-29. White Oak, Maryland: Naval Surface Weapons Center.

Method of computation of detonation parameters of condensed explosives. 1984. The Physics of Combustion and Explosion 20:83.

Modeling short duration shock initiation of heterogeneous explosives. 1985. In Proceedings of the Eighth Symposium (International) on Detonation, Albuquerque, New Mexico.

Monch Publishing Group. 1984. Military Technology. No. 1/84. Bonn, Federal Republic of Germany: Monch Publishing Group. January.

Naval Sea Systems Command. 1985. Technical Requirements for Insensitive Munitions. Draft Instruction. China Lake, California: Naval Weapons Center. February.

Naval Weapons Center. 1972. Safety and Peformance Test for Qualification of Explosives. NAVORD OD 44811. China Lake, California: Naval Weapons Center.

Pakulak, J., Jr. 1975. Characterization of Destex and Composition B (D-2 wax) Explosives. NWC TP 5433. China Lake, California: Naval Weapons Center. September.

Parkinson, J. L. 1975. Explosive Logic Circuits. Report LA-5802. Los Alamos, New Mexico: Los Alamos National Laboratory. January.

Pearson, J., and M. Lampson. 1985. Penetration Devices; Advanced Concepts. Briefing given by J. Pearson, (LCWSL) and M. Lampson (BRL), March 5, 1985.

Persson,tA. 1983. A theoretical analysis of the mechanics of tandem-shaped charges and their interaction with different targets. Paper given at the Swedish National Defense Research Institute. In Proceedings of the Seventh International Symposium on Ballistics, April 19-21, 1983, by the American Defense Preparedness Association.

Prather, J. G. 1985. In-house laboratory independent research. Army Research, Development and Acquisition Magazine (May/June).

Proceedings of the Fourth through Eighth Symposia (International) on Detonation. 1965 to 1985.

Randers-Pehrson, G. 1985. Smart Munition Concepts. Briefing given by G. Randers-Pehrson, LCWSL, March 4, 1985. Dover, New Jersey.

Rocchio, J. J. 1981. P. 511 in JANNAF Propulsion Meeting, Vol. III, May 26-28, 1981.

Ross, D. L., D. A. Levins, M. E. Hill, C. D. Bedford, and R. W. Woolfolk. 1982. High Energy Propellant Materials Research: A Technical Assessment. SRI International, Final Report. Contract F496210-81-k-0013. Menlo Park, California: SRI International. October.

Schaffer, M. B. 1974. Advanced Antitank Mine Technology. Report RDA-TR-4400-005-1, ARPA Order 2554. Santa Monica, California: R&D Associates. December.

Shuigen, X., et al. 1982. Research of the cylinder test. Explosions and Shock Waves 1:100.

Shvedov, K. K. 1981. Some Problems of the Detonation of Composite Explosives. Second All-Union Conference on Detonation, Chernogolovka, USSR.

Slagg, N. 1984a. Army Survey of U.S. Capability and Trends. Briefing given by Norman Slagg, November 27, 1985. Washington, D.C.

Slagg, N. 1984b. Survey of U.S. Energetic Materials Technology. Dover, N.J.: ARDC. November.

Smith, L. 1985. Letter to Dennis Miller, Executive Director, Board on Army Science and Technology with enclosure, "Recommended Fuel Air Explosive Technology Development Areas by Larry Josephson." China Lake, California: Naval Weapons Center. February 11.

Snowden, W. 1985. DARPA Armor/Anti-Armor Program. Briefing given by W. Snowden, DARPA, January 23, 1985. Washington, D.C.

Spencer, W., and H. H. Cady. 1981. The ammonium nitrate with 15 WT% potassium nitrate-ethylenediamine dinitrate-nitroguanidine system. Propellants and Explosives 6:99-103.

Stefanye, D. 1985. Energetic Materials Related R&D for Mine Neutralization. Briefing given by David Stefayne, Belvoir R&D Center, March 4, 1985. Fort Belvoir, Virginia.

Stein, A. 1985. Discussion with Dr. David Stefanye, Engineer Support Laboratory, Belvoir R&D Center, Fort Belvoir, Virginia. March.

Stein, A., and H. Hassmann. 1985. Telecon with H. Hassman of PM-CAWS, Dover, New Jersey, September 6, 1985.

Stein, A., and J. Ulrich. 1985. Trip Report--Visit to Picatinny Arsenal, Ballistics Research Laboratory and Chemical Research and Development Command. March 21-22.

Stevens, T., and A. King. 1985. Missile and Rocket Warhead Technology. Briefing given by Theodore Stevens and Al King, LCWSL, March 4, 1985. Dover, New Jersey.

Stine, J. R. 1981. Prediction of Crystal Densities of Organic Explosives by Group Additivity. Report LA-8920. Los Alamos, New Mexico: Los Alamos National Laboratory. August.

Stinecipher, M. M. 1984. Eutectic Explosives Containing Ammonium Nitrate. Final Report--October 1979 through September 1981. Report LA-9973-MS, UC-45. Los Alamos, New Mexico: Los Alamos National Laboratory. April.

Stinecipher, M. M., and L. A. Stretz. 1985. Sensitivity and performance characterization of DINGU. In Proceedings of the Eighth Symposium (International) on Detonation. Los Alamos National Laboratory, Albuquerque, New Mexico. Preprint.

Taylor, F. 1985. Requirements For, and Advances in, Pyrotechnology. Briefing given by F. Taylor, LCWSL, March 5, 1985. Dover, New Jersey.

Thurman, M. R. 1984. Interview reported in the Army Research, Development and Acquisition Magazine (November/December).

Titov, V., et al. 1985. Determination of transient and kinetic characteristics in simulating RDX/TNT 50/50 charge initiation. In Proceedings of the Eighth Symposium (International) on Detonation, Albuquerque, New Mexico.

Tulis, A. 1985. CANETIP for Mine Neutralization. Briefing given by Allen Tulis, IIT Research Institute, January 24, 1985. Chicago, Illinois.

USDR&E 79-653. 1979. DOD/DOE Study of Insensitive High Explosives and Propellants. C-NSI. March.

Voskobornikov, I. M., et al. 1981. Estimate of metal accelerating ability of explosives. P. 83 in The Physics of Combustion and Explosion V. 20.

Voskobornikov, I. M., et al. 1982. Effect of inert additives on the velocity of plates being accelerated by mixed explosives. Combustion, Explosion and Shock Waves 6.

Wackerle, J., et al. 1976. Shock Initiation of High-Density PETN. Proceedings of the Sixth Symposium (International) on Detonation, Coronado, California.

Walker, F. E. 1973 and 1974. Performance of Nonideal HE. Report UCID-16557 (1974) and UCID 16439 (1973). Livermore, California: Lawrence Livermore National Laboratory.

Weingart, R. C., et al. 1976. Acceleration of thin flyers by exploding metal foils: Application to initiation studies. In Proceedings of the Sixth Symposium (International) on Detonation, Coronado, California.

Wise, R. A., R. L. Blackly, and T. T. Connors, et al. 1980. A Model of Vehicle Activity in the Warsaw Pact Tactical Rear During a Conventional Attack Against NATO. Rand Corporation Report N-1495-AF. September.

Wu, X., et al. 1985. Detonation properties of condensed explosives computed with the VLW equation of state. In Proceedings of the Eighth Symposium (International) on Detonation, Albuquerque, New Mexico.

Xinghai, S., et al. 1982. An electric gun device. Explosions and Shock Waves 4:67.

Youmei, H., et al. 1982a. Oxygen-balanced explosives. Explosions and Shock Waves 1:106.

Youmei, H., et al. 1982b. Metal accelerating ability of several explosives. Explosions and Shock Waves 3:59.

Zeldovich, B., and A. S. Kompaneets. 1960. Theory of Detonation. New York and London: Academic Press.

Zhiying, C., et al. 1981. Detonation properties calculation of condensed explosives by LJD theory. Explosions and Shock Waves 2:96.

Zubarev, W. N. 1984. Equation on state of explosion products of condensed explosives. The Physics of Combustion and Explosion 20:102.

APPENDIX A

BIOGRAPHICAL SKETCHES

Robert A. Beaudet is professor of chemistry at the University of Southern California. He received his B.S. from Worcester Polytechnic Institute in Massachusetts and his Ph.D. in physical chemistry from Harvard University in 1962. From 1961 to 1962, he was a U.S. Army Officer and served at the Jet Propulsion Laboratory as a research scientist. Most of his career has been devoted to research in molecular structure and molecular spectroscopy. He has served for 12 years as a member of the Army Science Board and served as a member of numerous Army and Air Force study panels. He has also been a consultant in the areas of obscuration, chemical warfare, mines, and mine detection.

Karl O. Christie received his Ph.D. in Organic Chemistry in 1961 from the Technical University of Stuttgart. In 1962, he immigrated to the United States and joined the Western Research Laboratory of Stauffer Chemical in Richmond, California, as a research chemist working in the areas of high energy oxidizers and fluorocarbon chemistry of industrial interest. In 1967, he joined the technical staff of Rocketdyne in Canoga Park, California and in 1979 became manager of inorganic chemistry, devoting his time almost exclusively to contract research on energetic materials and propellants. He has authored or coauthored some 240 technical papers and patents in this field. In recognition of his work, Dr. Christie was awarded the 1986 ACS Fluorine Award for Creative Work in Fluorine Chemistry.

Harry L. Flaugh is Deputy Group Leader for Weapon Engineering at the Los Alamos National Laboratory, where he earlier served as group leader for explosives technology. He has conducted work on explosives research, development, and application, as well as on engineering development of nuclear weapon systems. He received his B.S and M.S in Chemical Engineering from the Iowa State University and worked for the Ames Laboratory before joining Los Alamos.

M. Frederick Hawthorne is professor of chemistry at the University of California, Los Angeles. He received his B.A. from Pomona College and his Ph.D. from UCLA. He was a science research chemist for Rohm and Haas Company at Redstone Arsenal, Alabama, and was later a laboratory head for Rohm and Haas Company in Philadelphia. Before accepting a position at UCLA in 1969, he was professor of chemistry at the University of California, Riverside. Dr. Hawthorne has published papers in the areas of exploratory synthesis, boron hydrides, and carboranes.

Marion E. Hill received his B.A. and M.A. degrees in organic chemistry from the University of Oregon and spent one year at The Pennsylvania State University for graduate study on a Navy Fellowship. He recently retired after 17 years as Chemistry Laboratory Director of the Physical Sciences Division of SRI International and has continued part time as Senior Scientific Advisor. From 1960 to 1968, Mr. Hill was chairman of the Organic Chemistry Department and senior research associate at SRI and worked in organic synthesis related to propellants and explosives. Between 1951 and 1960, he worked at the Navy Ordnance Laboratory, doing research on new high-energy chemical processes and products. He began his career at the National Bureau of Standards in thermochemistry. Mr. Hill has authored 34 publications and holds 22 patents in organic nitrocompounds, plasticizers, fluorination and fluorine compounds, nitration, and esterification. He has received numerous awards, including the Navy Meritorious Civilian Service award and a Navy award for the discovery of the formal process and the plasticizer bis dinitropropyl formal. He is also a consultant to BDM corporation and a volunteer executive of the International Executive Service Corporation.

John W. Kury is currently a staff scientist at the Lawrence Livermore National Laboratory in Livermore, California. He began his career at Lawrence Livermore in 1953 as a research chemist. He received a B.S. in Chemistry from the St. Louis University and a Ph.D. in Physical-Inorganic Chemistry from the University of California. Dr. Kury has conducted research in explosives performance, sensitivity, and formulation and has published many articles on the subject.

Arthur Stein received his B.S. in Mathematics from the College of the City of New York and his M.A. in Mathematical Statistics from Columbia University. Before becoming a private consultant, Mr. Stein worked at the Ballistics Research Laboratory, Cornell Aeronautical Laboratory (now Calspan), and Falcon Research and Development Company. His fields of interests are ballistics, operations research, and reliability and quality control, and he has done extensive work in survivability/vulnerability and lethality analyses, differential effects for artillery systems, munitions concept generation, requirements analyses and assessments of tactical guided missiles, and chemical warfare. He is the author or coauthor of more than 75 reports and papers in these areas. In addition to MORS and ADPA activity, he is a senior member of several professional societies, including the Operations Research Society of America, American Statistical Association, Society of Reliability Engineers, and American Society for Quality Control.

Martin Summerfield is chief scientist at Princeton Combustion Research Laboratories. He received his M.S. and Ph.D. in physics from the California Institute of Technology, and has served as research engineer, jet propulsion project, assistant chief engineer, and chief of the Rockets and Materials Division at the Jet Propulsion Laboratory and as chief of the Liquid Rocket Development Department, Aerojet Engineering Corporation. In addition, Dr. Summerfield has held the position of Professor of Aeronautical Engineering at Princeton University. He has served as a member of the National Academy of Engineering, American Physics Society, American Society of Mechanical Engineers, American Institute of Aeronautics and Astronautics, and International Academy of Astronautics. He has conducted research in areas such as infrared spectroscopy, soil erosion, rocket propellants, combustion, jet and rocket engines, and heat transfer.

John W. Taylor is currently a senior technical advisor in Defense Research Programs at Los Alamos National Laboratory. He received a B.S. in Physics from St. Lawrence University and a Ph.D. from Cornell University. He served as a staff member and technical leader of various weapon-related divisions and groups at Los Alamos for 28 years. From 1980 to 1982 he was on assignment to the U.S. Department of Energy as Chief Technical Advisor to the Director of Military Applications. In addition, he spent five years as a member of the USAF Scientific Advisory Board. Other areas of expertise include shock wave physics, applications of explosives technology, and military ordnance.

John A. Ulrich holds an A.B. in Engineering from Stanford University and has attended graduate courses in Industrial Engineering at the University of Pittsburgh. After 23 years of service, in the U.S. Army, mostly involved in research and development, manufacture and application of ammunition and weapons, from which he retired in 1964 with the rank of Colonel, Mr. Ulrich went to Chamberlain Manufacturing Corporation as vice president, Research and Development, retiring in 1980. His initial assignment at Chamberlain was to monitor operations at the Scranton and Burlington Army Ammunition Plants. At Scranton, he spearheaded a group assigned to expedite production of the 155mm M107 and the 175mm M437. He also was in charge of Chamberlain's participation in the rehabilitation program at Scranton. Currently, Mr. Ulrich is president of John A. Ulrich, Associates, Inc., a consulting firm.