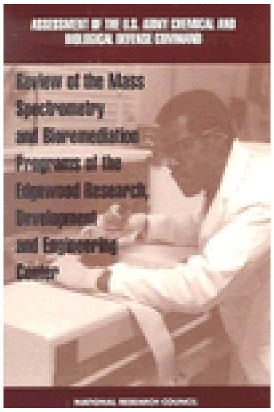

Review of Mass Spectrometry and Bioremediation Programs of the Edgewood Research, Development and Engineering Center

Standing Committee on Program and Technical Review of the U.S. Army Chemical and Biological Defense Command, National Research Council

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Assessment of the U.S. Army Chemical and Biological Defense Command

Standing Committee on Program and Technical Review of the U.S. Army Chemical and Biological Defense Command
Board on Army Science and Technology
Commission on Engineering and Technical Systems
National Research Council

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Preface

This report is the second of a two-phase response to a request from the technical director of the U.S. Army Edgewood Research, Development and Engineering Center (ERDEC) that the National Research Council (NRC) conduct technical assessments and reviews of programs in the command. The NRC was asked to conduct a technical assessment of the man-in-simulant test (MIST) program and a program review of the mass spectrometry and bioremediation programs. These programs represent a continuum of technologies designed to protect, detect, and dispose of the chemical and biological weapons soldiers may face in future combat. The first report, *Technical Assessment of the Man-in-Simulant Test (MIST) Program* was published in 1997. This second report focuses on the program review of the mass spectrometry and bioremediation programs.

Members of the NRC Committee have a wide range of expertise in protective systems, toxicology, risk assessment, environmental and occupational health, simulation and modeling, textile science, human factors, organic chemistry, biochemistry, mass spectrometry, and chemical engineering. Of these, the members with special expertise relevant to reviewing the mass spectrometry and bioremediation programs were chosen to serve on the reviewing committee. Some of them have been with the committee since its formation and have benefited from the knowledge gained from the earlier study. The committee met twice, in October 1997 and February 1998, and interviewed members of both of the ERDEC groups, as well as senior managers of the ERDEC Research and Technology Directorate (RTD).

In this report, the committee assesses the technical character of the programs and the processes used to achieve their goals. The assessment was complicated by some changes in personnel and a significant change in the ERDEC organizational structure between the first and second visits. Also, a new director of the RTD has since assumed his position and is in the process of establishing his style and making changes to the corporate culture.

The chair and the committee wish to thank the NRC staff for its assistance and support. We are indebted to Bruce Braun, director, Board on Army Science and Technology; George Davatelis, study director until December 1997; Edward Downing, study director since December 1997; Jacqueline Campbell-Johnson and Pamela Lewis, senior project assistants for the respective study directors; Margo Francesco, staff associate; Alvera Wilson, financial associate; and Norman Haller, consultant. The work of the committee would not have been possible without these dedicated individuals. The committee also appreciates the comments of the various groups that agreed to be interviewed and the group of outside experts who graciously donated their time to review this report.

The committee would like to express its special appreciation to committee member Dr. Clement Furlong of the University of Washington for his valuable contributions to the report up until his departure in early 1998.

FRANCIS G. DWYER, CHAIR

STANDING COMMITTEE ON PROGRAM AND TECHNICAL REVIEW OF THE U.S. ARMY CHEMICAL AND BIOLOGICAL DEFENSE COMMAND

Acknowledgment

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the National Research Council in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Albert Venosa, U.S. Environmental Protection Agency, Cincinnati, Ohio
Fred McLafferty, Cornell University, Ithaca, New York

Rob Staffan, Environgen, Inc., Lawrenceville, New Jersey

George W. Parshall, DuPont Company, Wilmington, Delaware

Anne Street, GEO-CENTERS, Rockville, Maryland

Wayne Askew, University of Utah, Salt Lake City

While the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring committee and the National Research Council.

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Tables, Figures, and Boxes

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BOX

Acronyms

CB	chemical and biological
CBD	chemical and biological defense
CBW	chemical and biological warfare
CBDCOM	Chemical and Biological Defense Command
CSC	CBDCOM Standing Committee on Program and Technical Review of the U.S. Army Chemical and Biological Defense Command
CW	chemical warfare
CWA	chemical warfare agent
DETA	diethylenetriamine
DOD	U.S. Department of Defense
DS2	decontaminating solution 2
EGME	ethylene glycol monomethyl ether
ERDEC	Edgewood Research, Development and Engineering Center
ESI	electrospray ionization
ETT	Environmental Technology Team
MALDI	matrix-assisted laser desorption/ionization
MIST	man-in-simulant test
MS/MS	mass spectrometer/mass spectrometer (any device that records the product ion spectrum generated from a precursor ion)
NRC	National Research Council

ORNL	Oak Ridge National Laboratory
RD&E	research, development, and engineering
RTD	Research and Technology Directorate
TOF	time of flight
VX	a chemical warfare nerve agent

Executive Summary

BACKGROUND

In 1993, the U.S. Army established the Chemical and Biological Defense Command (CBDCOM) to conduct research, develop and procure support systems, and design equipment to protect U.S. military personnel from chemical and biological weapons used by foreign military forces and terrorist organizations. The CBDCOM is the latest in a long line of military organizations designated for chemical and biological defense research. Because of the critical nature of its mission, the CBDCOM requested that the National Research Council (NRC) establish an oversight committee of nationally recognized experts to provide ongoing, impartial, independent advice.

The NRC, responding through the Board on Army Science and Technology of the Commission on Engineering and Technical Systems, created the Standing Committee on Program and Technical Review of the U.S. Army Chemical and Biological Defense Command, better known as the CBDCOM Standing Committee (CSC). This committee was assembled to provide expertise in the areas of science and technology pertinent to the concerns of the CBDCOM commander and executive director and the technical director of the Edgewood Research, Development and Engineering Center (ERDEC), which historically has been an important organization for chemical and biological research in the Army and the U.S. Department of Defense.

The committee was asked to consider technological issues and systems to assist the CBDCOM in defining a vision for the future. After numerous visits and interviews with key personnel at the ERDEC and the CBDCOM and internal deliberations, the committee focused on two major areas: (1) a technical assessment of the man-in-simulant test (MIST) program; and (2) a review of the processes and technical character of ERDEC's mass spectrometry and bioremediation programs. The results of the assessment of the MIST program are documented in a 1997 NRC report, *Technical Assessment of the Man-in-Simulant Test (MIST) Program*. The present report addresses the ERDEC's mass spectrometry and bioremediation programs.

CURRENT STUDY

For this study, the committee was guided by the Statement of Task that directed the committee to "review the processes used by two representative, but very different ERDEC programs, mass spectrometry and bioremediation, to move basic research results and technology through development." The Statement of Task also directed the committee to comment on the "technical character of the two teams, since those processes must be assumed to affect overall technical quality," and, among other things, to review the procedures to "promote an overall quality focus."

THE PROGRAMS UNDER REVIEW

The mass spectrometry and bioremediation groups belong to two different ERDEC teams. The mass spectrometry group is part of the Chemical and Biological Point Detection Team, and the bioremediation group is part of the Environmental Technology Team.

The mass spectrometry group is composed of the following three subgroups:

- the thermal degradation subgroup, whose objective is to determine whether analyses of the thermal degradation products of spores, bacteria, viruses, and proteins can be used as biomarkers
- the laser-based spectrometry subgroup, whose objective is to develop laser-based approaches to agent detection
- the direct mass spectral analysis subgroup, whose objective is to use matrix-assisted laser desorption/ionization (and electrospray ionization in the future) to obtain mass spectrometric fingerprints of spores, bacteria, viruses, and proteins by direct mass spectral analysis with the aim of identifying selected materials on the Department of Defense threat list.

The bioremediation group consists of 12 people who were working on 11 projects in fiscal year 1997 and 13 projects in 1998 including the following:

- The largest project, Enzymatic Decontamination, is the development of a new generation of chemical-biological warfare decontaminants based on catalytic enzymes. Unlike current decontaminants, these will be nontoxic, noncorrosive, nonflammable, and environmentally safe.
- The Alternative Technologies Program is focused on the demilitarization of chemical weapons stockpiles. Its objective is to develop biotechnical means for destroying the stockpiles of chemical agents as an alternative to incineration.
- A third project is the Biodegradation of Decontaminating Solution 2 (DS2). DS2, the current decontaminant in the Army inventory, is effective, but it is also toxic, flammable, and highly corrosive.

APPROACH

The data for this study were derived from two interview sessions and from responses to written questionnaires. The committee developed an assessment model of five categories subdivided into 31 characteristics (Table ES-1). Each of the 31 characteristics was described in terms of four stages of maturity.

Interviews were conducted on two occasions, in October 1997 and February 1998. For the first interviews, the committee was divided into three teams based on the assessment categories and each member's background and experience. In the second set of interviews, the committee focused on the technical capabilities of the two groups and the effects of the Research and Technology Directorate (RTD) management on the research programs.

Because the Statement of Task required the committee to focus on quality, the committee has commented extensively on the effectiveness of the quality management programs of the two groups at the time of the interviews. The topics listed below are some of the aspects of quality management touched on in this report:

- identifying customers and customers' needs
- focusing on the mission
- sharing information

TABLES ES-1 Categories and Characteristics of the Assessment Model

- **ASSESSMENT MODEL**[a]

- **Customer Focus**
- Customer
  - Customer satisfaction
  - Customer involvement
  - Market diversification
- **Resources and Capabilities**
- Organizational culture
  - Employee attitude
  - People development
  - Budget/funding
  - RD&E capabilities, skills, and talents
  - Intellectual property
  - Technology sourcing
  - Information technology
  - Facilities and infrastructure
- **Strategic Vision**
- Mission and vision
  - Strategic planning
  - Stakeholder[b] buy-in
  - Leadership
- **Value Creation**
- Portfolio[c] selection
  - Cycle time and responsiveness
  - Value of work in progress
- **Quality Focus**
- Capacity for breakthroughs
  - Continuous improvement
  - Teams
  - Evaluation and rewards
  - Project management
  - Regulatory compliance
  - Commitment to quality
  - Process management
  - Metrics
  - Safety
  - Knowledge and Learning

- [a] See also NRC, 1996. World-Class Research and Development Characteristics for an Army Research, Development, and Engineering Organization. Washington, D.C.: National Academy Press.
- [b] Stakeholders refer to any group that has a stake in the success of the organization. In the case of the mass spectrometry and bioremediation groups, the stakeholders include employees, ERDEC and CBDCOM management, members of the "Executive Panel," scientific peers, etc.
- [c] The term "portfolio" refers to the collection of research projects of an organization.

- teamwork at all levels
- using performance metrics
- benchmarking (learning from others)
- using project management
- establishing a corporate culture that fosters quality management

Management is responsible for ensuring that the program focuses on quality at all levels of the organization. Although the primary purpose of this study is to review, the committee also suggests ways both groups could improve.

The committee members pooled their experience and expertise to prioritize the areas of each program that need management's attention. Each program was described in terms of the 31 characteristics of the Assessment Matrix, and each characteristic was rated on a maturity scale of 1 to 4 and an "importance" scale of 1 to 4 (1 = low). The characteristics were then prioritized in terms of the need for improvement. Priorities were expressed on a scale of 1 to 12 (1 = low) based on a combination of the maturity and importance measures.

MASS SPECTROMETRY

Findings

Although the mass spectrometry group is progressing toward its goals of identifying biomarkers for bacteria, spores, and proteins, is working on protein biomarkers using electrospray ionization methods, and is developing a battlefield CW detector, improvements could be made in several areas. First, the committee was concerned about the lack of mission focus of the portfolio of projects. The selection of projects seems to have been driven by the technical interests of the scientists rather than by the mission of the RTD. Second, the mass spectrometry group could improve its internal communications and teamwork. The committee found that the three mass spectrometry subgroups had a competitive, rather than cooperative, attitude toward each other. Thus, they worked in relative isolation from each other and did not share ideas or results. Third, the program has highly sophisticated equipment but not enough qualified technicians to operate it. Fourth, metrics are not used to assess progress. Fifth, in 1997, an independent "Executive Panel" of 23 specialists in mass spectrometry drawn from government and academia made several recommendations for improving the ERDEC's mass spectrometry program. The committee noted that the mass spectrometry group has not followed these recommendations.

Finally, the committee is concerned about the fundamental question of whether mass spectrometry is the best way to detect and identify biological agents. The committee notes that there are other methods that should be investigated, such as immunological methods and other antibody/antigen-based systems.

The following characteristics of the mass spectrometry group received the highest priority score of 12 indicating that they need the most urgent attention: Commitment to Quality, which encompasses training, focus, dedication, and the many activities espoused in the Baldrige National Quality Award[1] and the ISO[2] criteria; Metrics, which includes measures for evaluating the progress of an organization in key functions; Leadership, the ability of management to create an atmosphere of commitment throughout the organization; and Organizational Culture, an atmosphere in which people are valued and respected for their skills.

Conclusions

Conclusion 1. The subgroups of the mass spectrometry group were not able to identify their customers or their customers' needs.

Conclusion 2. The work of the mass spectrometry group is not cohesively focused on its mission.

Conclusion 3. The three mass spectrometry subgroups work in relative isolation from each other and do not regularly share ideas or results.

Conclusion 4. The mass spectrometry group does not make full use of its sophisticated, expensive equipment.

Conclusion 5. The mass spectrometry group does not use performance metrics to evaluate continuous improvement.

Conclusion 6. The priorities and recommendations of the Executive Panel have not been followed.

Conclusion 7. Mass spectrometry may not be the best system for detecting and identifying biological agents.

[1] The Baldrige National Quality Award was established by Congress in 1987 to recognize U.S. companies for their achievements in quality and business performance and to raise awareness of the importance of quality and performance as competitive advantages.

[2] The ISO 9000 series of International Standards for quality management and quality assurance has been adopted in more than 90 countries and is being implemented by thousands of manufacturing or service organizations, both public and private.

Recommendations

Recommendation 1. The leadership of the mass spectrometry group should focus the work of the overall program by defining the mission and goals, setting scientific priorities, ending internal competition, and promoting cooperation, including data sharing.

Recommendation 2. The management of the Research and Technology Directorate should bring all three subgroups of the mass spectrometry group into one laboratory complex.

Recommendation 3. As soon as possible, the senior management of the Research and Technology Directorate should evaluate, with the assistance of outside experts, the effectiveness of mass spectrometry for detecting and identifying biological agents compared to other approaches, such as immunological methods, polymerase chain reactions, and other antibody/antigen-based systems. In addition, senior management should seek an independent evaluation of the recommendations made by the Executive Panel.

Recommendation 4. The mass spectrometry subgroups should interact closely with other groups working with polymerase chain reactions, flow cytometry, and other immunological detection systems to compare the performance levels (e.g., analytical specificity and sensitivity) of these technologies. If mass spectrometry does not perform at an equal or higher level, the mass spectrometry group should develop a program that would meet the highest performance requirements. This program should then be evaluated by the management of the Research and Technology Directorate for its feasibility.

Recommendation 5. The scientific capabilities and research projects of all three mass spectrometry subgroups should be evaluated in relation to the recommendations of the Executive Panel to help management make optimum assignments. Once priorities have been established for the mass spectrometry group, tasks should be assigned to the subgroups according to their scientific capabilities.

Recommendation 6. The sophisticated, expensive equipment should be fully used.

Recommendation 7. The mass spectrometry group and management of the Research and Technology Directorate should develop and implement performance metrics to measure progress.

BIOREMEDIATION

Findings

The *esprit de corps* in the bioremediation group was high among both employees and contractors. The quality of leadership was also high, and information between management and staff flowed in both directions. An air of excitement pervaded the laboratory, risk-taking was encouraged, and leads were quickly pursued. Nevertheless, several areas could be improved. First, portfolio selection appears to be technology driven rather than mission driven. Also, there has been little input from the intelligence community about potential new threats that could be useful for mission-oriented project selection. Second, the bioremediation group has no formal process for the selection of, and techniques and criteria for, outsourcing projects. Third, scientists have no opportunity to learn about related work being done in other parts of the RTD. Fourth, principal investigators receive no feedback during the proposal funding process. In other words, no explanations or critiques are offered explaining why proposals are not chosen for funding. Finally, annual Technology Base Reviews could be used to improve communication among technology teams.

The highest priorities for management attention are Commitment to Quality, which encompasses training, focus, dedication, and the many activities espoused in the Baldrige National Quality Award and ISO criteria; and Metrics, which includes measures for evaluating progress in key areas.

Conclusions

Conclusion 1. The quality of leadership in the bioremediation group is high. Information flows in both directions between management and staff, and an air of excitement pervades the laboratory. *Esprit de corps* is shared by both employees and contractors.

Conclusion 2. Although the portfolio seems to meet the strategic goals of the group, the overall program appears to be technology driven rather than mission driven.

Conclusion 3. The bioremediation group does not have a formal process for selecting research to be outsourced (i.e., funded at a university, other government laboratory, or corporate laboratory) or established criteria for making outsourcing decisions.

Conclusion 4. Project management, including commitment to quality and metrics, could be greatly improved. For example, an adaptation of the stage-gate model might be used.

Conclusion 5. The bioremediation group does not have opportunities to work with related groups in the Edgewood Research, Development and Engineering Center.

Conclusion 6. The bioremediation group is given little or no feedback on the reasons technical proposals are funded or rejected.

Conclusion 7. The bioremediation group is not kept up to date on intelligence estimates of biological and chemical agents being developed by potentially threatening groups and countries. This lack of information interferes with the selection of mission-oriented projects.

Recommendations

Recommendation 1. The portfolio of the bioremediation group should be linked to the larger mission of the organization. This can be facilitated by frequent intelligence briefings on biological and chemical agents that are being developed or are already in the arsenals of foreign countries.

Recommendation 2. The bioremediation group should establish a more formal process for making decisions on outsourcing and for managing outsourced projects.

Recommendation 3. The bioremediation group should establish a formal project management process to facilitate learning and improve efficiency.

Recommendation 4. Management should internally publish all funded proposals and critiques and should provide principal investigators with critiques of unfunded proposals.

Recommendation 5. The leadership of the Research and Technology Directorate should use annual Technology Base Reviews for sharing information among all technology teams.

MANAGEMENT

Findings

The committee found no evidence that the project portfolios of the mass spectrometry and bioremediation groups are coordinated by an overall strategy. Information is not exchanged freely among the staff. In the mass spectrometry group, contractors and government staff are both dissatisfied with their working relationships. Senior scientists are handicapped by having to perform tasks that could be performed by technicians. Finally, the committee believes that long-term basic research cannot be conducted effectively by either of the two groups because the time limitations imposed by annual funding and the corresponding procedure favor short-term projects.

Conclusions

The following conclusions, which pertain to both groups reviewed by the committee, may also apply to the RTD at large.

Conclusion 1. The corporate cultures of the mass spectrometry and bioremediation groups are not conducive to a free exchange of information among the staff.

Conclusion 2. Quality management principles have not been incorporated into the everyday operations of the mass spectrometry or bioremediation groups.

Conclusion 3. The project portfolios of the mass spectrometry and bioremediation groups are not well balanced and are not coordinated by an overall strategy.

Conclusion 4. Both contractors and government staff in the mass spectrometry and bioremediation groups are dissatisfied with their working relationships.

Conclusion 5. Because the time limitations imposed by the annual funding mechanism and the corresponding procedure favor the selection of applied research projects, neither the mass spectrometry nor the bioremediation group can effectively conduct long-term basic research.

Recommendations

Because these conclusions and recommendations are based on a small sample, the committee strongly suggests that the management of the Research and Technology Directorate review other groups to determine if the following recommendations apply to them.

Recommendation 1. Senior management should ensure that cultural changes are made that support quality management.

Recommendation 2. Senior management should establish a strategy, set goals, and define the mission for all of the laboratories. Coordinated portfolios of projects should be based on the needs of the customer, the overall strategy, and the mission of the Research and Technology Directorate, as well as on the resources and capabilities available both in-house and from outside contractors.

Recommendation 3. Management should encourage a spirit of teamwork between contractors and government staff; investigate types of contracts that allow better day-to-day management of contractors on site; ensure that both government staff and contractors are completely familiar with the rules under which they both must work; and eliminate unnecessary obstacles, perceived or actual, to the contractors doing their jobs.

Recommendation 4. Senior management should consider hiring more technicians to leverage scientists' and technicians' singular capabilities.

Recommendation 5. The Research and Technology Directorate should de-emphasize in-house, long-term, basic research and should use these funds to sponsor research with universities or transfer projects to external Army agencies that are more clearly associated with long-term basic research. The organization could then focus on practical applications of new technologies. (This recommendation may not be applicable to all groups but should be considered in future evaluations of the organization.)

1

Introduction

BACKGROUND

The purpose of chemical and biological defense research is to develop equipment that will protect U.S. military forces, sustain combat operations, and maintain system effectiveness in an environment contaminated by chemical or biological agents. The cornerstone of the defense strategy is early detection and warning so steps can be taken to prevent the exposure of personnel and equipment. The complement to detection is protection (i.e., to insulate personnel from chemical or biological agents with individual clothing ensembles and respirators, as well as collective filtration systems and shelters). Modeling and simulation technologies are used to assess conditions, train personnel, and develop materiel for operating in an environment contaminated by chemical or biological agents, develop parameters for equipment design, and enable field commanders to integrate and interpret real-time data.

In 1993, the Army established the U.S. Army Chemical and Biological Defense Command (CBDCOM), which is responsible for nuclear, biological, and chemical defense, technology, products, and services to support U.S. forces, ensure the safe storage of chemical materiel, oversee remediation and restoration after exposure, and support chemical treaties and demilitarization. The Research and Technology Directorate (RTD) of the Edgewood Research, Development and Engineering Center (ERDEC), which is part of the CBDCOM, performs research and development for biological, and chemical defense programs for the Army.

In 1995, the CBDCOM requested that the National Research Council (NRC) provide expert, impartial, independent advice on various aspects of its activities and programs. In response to this request, the NRC organized the Standing Committee on Program and Technical Review of the U.S. Army Chemical and Biological Defense Command, referred to here as the

CBDCOM Standing Committee (CSC). This committee was assembled to provide expertise in the areas of technology pertinent to CBDCOM's mission, which includes five primary areas:

- maintaining a chemical and biological defense technology base and procurement capability
- relating the results of tests on chemical and biological defense equipment to battlefield performance
- informing the Army, Congress, and the public about chemical and biological issues
- transferring defense technology to potential users
- integrating CBDCOM's technology and advanced concepts with the work of the Army's battle laboratories

The CSC was asked to consider technological issues and systems to assist the CBDCOM in defining a vision for the future. During its first year, the CSC was also asked to evaluate potential studies that would address the concerns of the CBDCOM commander and executive director and the technical director of the ERDEC, which has historically been an important organization in the Army and the U.S. Department of Defense (DOD) for chemical and biological research.

After numerous visits and interviews with key personnel at the ERDEC and the CBDCOM and internal deliberations, the CSC focused on two major areas: (1) a technical assessment of the man-in-simulant test (MIST) program; and (2) a review of the processes and technical character of the ERDEC's mass spectrometry and bioremediation programs. The results of the assessment of the MIST program were documented in a 1997 NRC report (NRC, 1997). The present (second) report focuses on the ERDEC's mass spectrometry and bioremediation programs.

CHARGE TO THE COMMITTEE

The CSC was guided by the following Statement of Task:

> The committee proposes to review the processes used by two representative, but very different ERDEC programs, mass spectrometry and bioremediation,[1] to move basic research results and technology through

development. Although the review will consider the processes used by the two programs, it will necessarily include comment upon the technical character of the programs conducted by the two representative teams, since those processes must be assumed to affect overall technical quality. The CSC will review the procedures used to:

1. acquire, retain, and develop research and engineering capabilities, skills and talents;
2. assess those processes associated with developing or acquiring technological solutions to fulfill materiel requirements;
3. promote an overall quality focus by maintaining high technical standards and continuously improving research, product quality, and productivity; and
4. assess customer satisfaction with the technological solutions and products delivered, the timeliness of the product delivery, and product support capabilities provided.

The committee defined three terms in the Statement of Task: basic research, procedures, and materiel. The time element of "basic research" is important in this report. As stated in the DOD Basic Research Plan, "DOD basic research will focus on a variety of military problems, some requiring near-term, immediate, or partial solutions, and others requiring sustained investment over longer periods to attain success" (DOD, 1997). In this report, the committee distinguishes between long-term basic research projects that take more than one year and short-term basic research projects that take less than one year. The committee did not interpret the term "procedures" in the Statement of Task to mean the written procedures at the ERDEC, a review of which would have entailed a desk audit of human resources. The committee assumed that the processes used to move basic research results and technology through development incorporated the procedures and, by examining the processes, the efficacy of the procedures would become apparent. The term "materiel," as used by the Army Materiel Command, of which CBDCOM is a part, is a more inclusive term than "material." Materiel includes research, development, engineering, storage, and distribution of supplies and equipment.

DIFFERENCES BETWEEN THE MASS SPECTROMETRY AND BIOREMEDIATION PROGRAMS

The two "representative, but very different" programs are both part of the ERDEC's Research and Technology Directorate, one of four directorates

[1] Bioremediation is the term CBDCOM uses to describe the destruction, by biological or biologically-derived materials, of chemical agents stored in weapons and other chemicals of military interest.

in the ERDEC organization (Figure 1-1). The bioremediation group is part of the Environmental Technology Team, and the mass spectrometry group is part of the Chemical Biological Point Detection Team. These groups were selected for review because of their different ways of doing business. Table 1-1 lists these differences in business approach, some of which have become less pronounced since this study began but may account for some of the differences that were found between the groups.

STUDY APPROACH

The CSC is composed of experts in the fields of protective systems, toxicology, risk assessment, environmental and occupational health, simulation and modeling, textile science, human factors, organic chemistry, biochemistry, mass spectrometry, and chemical engineering. The committee adopted the following approach to fulfilling the Statement of Task.

First, the committee developed metrics to evaluate various aspects of input, operations, production, and results in the ERDEC's laboratories. This methodology was based on the categories and characteristics identified in an earlier NRC report, World-Class Research and Development (NRC,) 1996), but was tailored to meet the unique characteristics of the RTD mass spectrometry and bioremediation laboratories. The committee then reviewed both groups according to these metrics.

BASIC FOR THE REVIEW

Data gathering for this study was done during two interview sessions, the first in October 1997 and the second in February 1998, and from responses

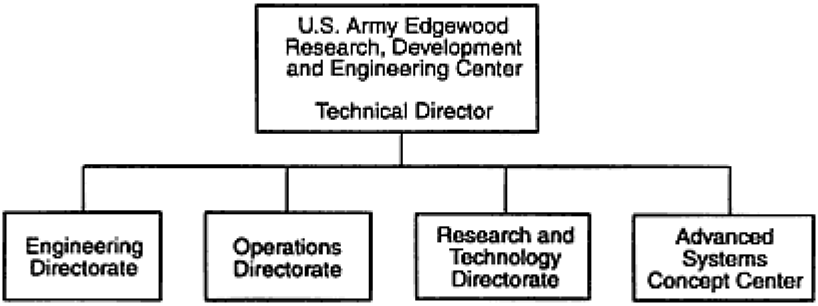

Figure 1-1
The ERDEC organization.

Table 1-1 Differences in the Business Approaches of the Mass Spectrometry and Bioremediation Programs

Mass Spectrometry	Bioremediation
Mostly mission funded	Mostly customer funded
Includes several outside participants	Mostly in-house workers
Focused on one common objective	Addresses a series of small problems

to written questionnaires. The second interview session was less structured than the first and gave the CSC enough latitude to follow whatever lines of inquiry seemed important to the review. The committee created an assessment model by integrating the model developed in the 1996 NRC study with a model based on current technology management and best-practice bench-marking studies (Ransley, 1997). The resulting model includes 31 characteristics divided into five categories: Customer Focus, Resources and Capabilities, Quality Focus, Strategic Vision, and Value Creation. The Assessment Model is outlined in Table 1-2 (see Appendix A for details).

Although the characteristics provided the structure for the program review, professional judgment played a significant role in the committee's assessment. The model defines four stages of maturity for each characteristic, from Stage 1, which describes an organization that urgently needs to improve, to Stage 4, which describes a top-ranked organization with respect to that characteristic (Box 1-1). The characteristics are shown in Table 1-2 under their respective categories.

The CSC was divided into teams based on the background and experience of the committee members. Three teams were formed for the first interviews, during which the ERDEC mass spectrometry and bioremediation groups were assessed based on the five categories in the model. One team was assigned the Resources and Capabilities category, one the Quality Focus category, and one the Customer Focus, Strategic Vision, and Value Creation categories. Each group was divided into clusters of three or four people, with contractors and government employees separated at the interviewees' request. The clusters moved from one CSC interview team to another. The CSC was reorganized for the second interview session into three different teams, one each to review the technical capabilities, skills, and talents of the mass spectrometry and bioremediation groups and one to review the effects of management outside the RTD on both groups.

Two approaches were used to gather data: written responses to questionnaires and oral interviews. The questionnaires were intended to establish the stage of maturity for each characteristic. The questions were of two types, closed and open. In the closed questions, scientists were asked to evaluate their work by choosing one of four descriptions corresponding to the four stages of maturity. In the open questions, scientists were asked to choose all items that pertained from a list of descriptions.

Table 1-2 Categories and Characteristics of the Assessment Model

ASSESSMENT MODEL[a]	
Customer Focus	**Value Creation**
Customer	Portfolio[c] selection
Customer satisfaction	Cycle time and responsiveness
Customer involvement	Value of work in progress
Market diversification	
Resources and Capabilities	Quality Focus
Organizational culture	Capacity for breakthroughs
Employee attitude	Continuous improvement
People development	Teams
Budget/funding	Evaluation and rewards
RD&E capabilities, skills, and talents	Project management
Intellectual property	Regulatory compliance
Technology sourcing	Commitment to quality
Information technology	Process management
Facilities and infrastructure	Metrics
	Safety
	Knowledge and Learning
Strategic Vision	
Mission and vision	
Strategic planning	
Stakeholder[b] buy-in	
Leadership	

[a] See also NRC, 1996. World-Class Research and Development Characteristics for an Army Research, Development, and Engineering Organization. Washington, D.C.: National Academy Press.
[b] Stakeholders are groups that have a stake in the success of the organization. In the case of the mass spectrometry and bioremediation groups, the stakeholders include employees, ERDEC and CBDCOM management, members of the Executive Panel, scientific peers, etc.
[c] The term "Portfolio" refers to the collection of research projects of an organization.

BOX 1-1 EXAMPLE OF THE FOUR STAGES OF MATURITY

CHARACTERISTIC	STAGE	DESCRIPTION
Metrics	Stage 1	Focus is on the short term.
	Stage 2	Measures include customer satisfaction; the goal is to ensure that customer requirements are met; the search is for "the few key measures" of progress toward that goal.
	Stage 3	A variety of measures linked to corporate goals are used; the organization recognizes that different measures are needed for different purposes; measures related to cost, time, and quality are used.
	Stage 4	A balanced list of measures is used to ensure that all key aspects of the organization are considered, including financial, external and internal customers, innovation and learning, and societal perspectives; the emphasis is on measuring customer value.

The responses to the questionnaires turned out to be less valuable than the interviews. This was partly because some respondents did not cooperate fully. Problems with the responses included multiple answers where a single choice was called for, "N/A" being offered as a response to issues that the assessment team had already determined to be important, internal inconsistencies, and less than a 50 percent return of questionnaires. Some of the inconsistencies reflected the respondents' lack of understanding of the issues being addressed in the questionnaire. During the interviews, the CSC was able to clarify topics and pursue some important issues in greater depth. Based on comments during the interviews, the committee was able to determine the stage of maturity that best described each characteristic.

The committee then weighted the characteristics to reflect their importance. The weighting was based on the expert judgments of committee members and was used consistently throughout the review to prioritize issues that surfaced during the interviews and in the written responses.

PREVIEW

This report summarizes the committee's activities, findings, conclusions, and recommendations. Chapter 2 focuses on the mass spectrometry group. Chapter 3 focuses on the bioremediation group. Chapter 4 presents management issues that were suggested to the committee during the reviews.

2

Mass Spectrometry

DESCRIPTION

The mass spectrometry group, also called the biological point detection group, is part of the Chemical and Biological Point Detection Team, which is one of approximately 24 teams that report to the director of the Research and Technology Directorate of the ERDEC (Figure 2-1). The mass spectrometry group is not formally organized and does not have a separate leader but is composed of government principal investigators (PIs) and government and contractor staff. The group consists of nine, people, four government employees and five contractors who are divided into three subgroups, each consisting of a PI and one or more staff members. The PIs report to the leader of the Chemical and Biological Point Detection Team. These subgroups will be discussed in greater detail in the Technical Capabilities section.

In 1997, a group of 23 specialists in mass spectrometry from government, industry, and academia (including six from the ERDEC) were invited by members of the mass spectrometry group to recommend priorities for future work in mass spectrometry. This "Executive Panel," chaired by Professor Donald F. Hunt, University of Virginia, met on July 31 and August 1, 1997. The panel was asked how the mass spectrometry group, by the year 2000, could best meet the goal of developing a small, mobile, reliable, fully automatic, quick-response, unmanned, remotely controlled, hardened chemical biological-mass spectrometry unit for use on the battlefield. The panel established the following priorities based on the limited funds and short time available:

1. Use proteins as "biomarkers."
2. Use electrospray ionization (ESI) to ionize the analytes and MS/MS for confirmation.

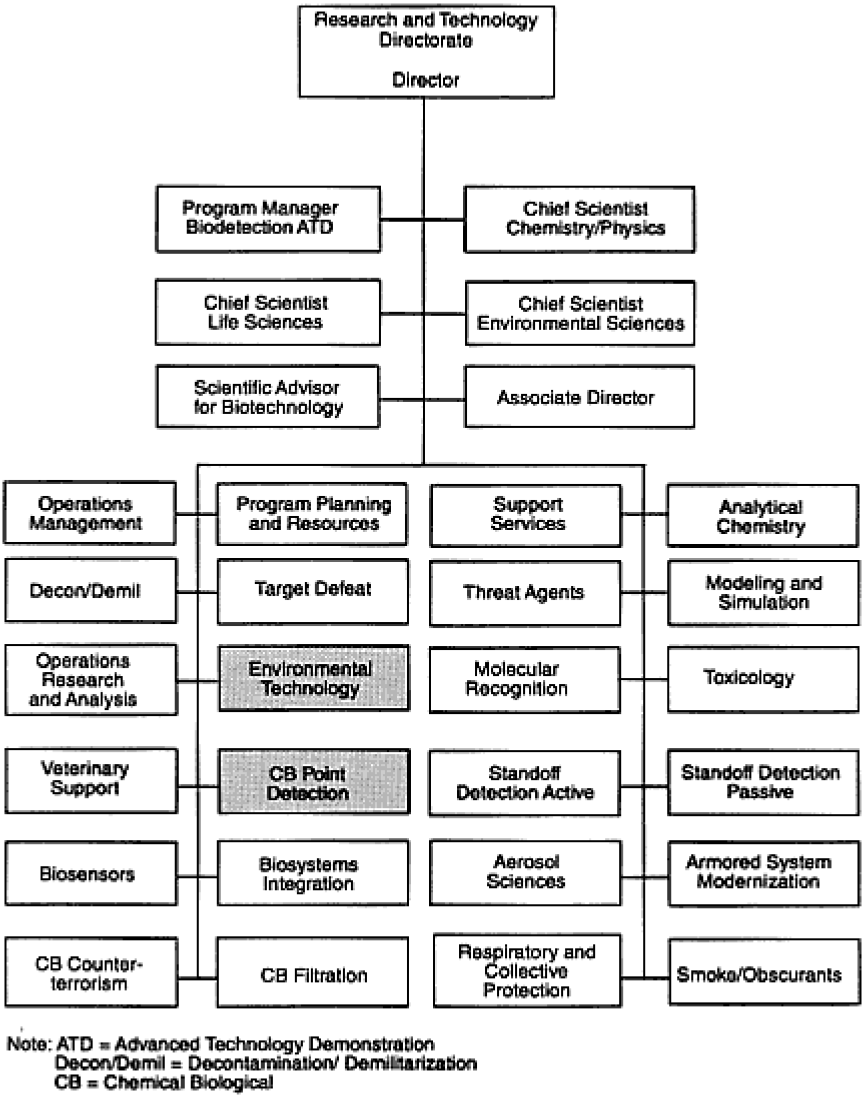

Figure 2-1
The Research and Technology Directorate of the ERDEC.

3. Use an ion trap as the mass spectrometer.
4. Develop a "front end" for sample processing. ("Front end" refers to the part of the instrument that processes the sample for introduction into the ion source of the mass spectrometer.)
5. Explore phospholipids as biomarkers.

6. Explore matrix-assisted laser desorption/ionization (MALDI) as a possible long-term solution in place of ESI.

The mass spectrometry group is investigating two technologies, mass spectrometry and, to a much lesser extent, ion mobility spectrometry, to determine their feasibility for detecting biological warfare agents in the field. The group is using several ionization techniques to develop a library of biomarkers for biological agents. Using the MALDI technique, the group has identified biomarkers for more than 90 of approximately 100 bacteria, spores, and proteins, both pathogenic and nonpathogenic. The group is now beginning to work on protein biomarkers using ESI-MS/MS methods.

The mass spectrometry group also participates in joint field trials to verify technologies and methodologies for sample extractions and sample preparations for standardizing the spectrum with ionization and pyrolysis techniques.

TECHNICAL CAPABILITIES

All of the subgroups in the mass spectrometry group use mass spectrometry technology, but each has a different approach to the overall mission, namely improving the methodology for chemical-biological point detection. The work of the subgroups is discussed below.

Thermal Degradation

The objective of the first subgroup is to determine whether analyses of the thermal degradation products of spores, bacteria, viruses, and proteins can be used as biomarkers. BG spores, *B. subtilis, Erwinia herbicola,* MSII, and ovalbumin are being used as simulants for biological agents of a limited number of compounds or agents on DOD's threat list. The subgroup is attempting to improve the pyrolysis of these materials to limit their thermal degradation and produce larger fragments (mass 600 and higher) of the parent materials. When the larger fragments are then analyzed in a mass spectrometer, the resulting mass spectra should provide a more characteristic chemical fingerprint of the parent compound than conventional pyrolysis, which causes much more severe degradation and smaller fragments (mass 150 and lower).

The larger fragments are produced by quickly flushing the material out of the pyrolysis zone using air rather than helium as the flushing gas, which makes the system more suitable for use in the field. This "gentle pyrolysis" method also makes it possible to detect dipicolinic acid (pyridine-2,6-dicarboxylic acid), a major component (~10 percent by weight) of the cell wall of spores, directly rather than after degrading it to the less characteristic pyridine. These improvements are expected to increase the sensitivity and specificity of the pyrolysis-mass spectrometry compared with the current chemical and biological agent mass spectrometry.

The thermal degradation subgroup is also investigating the use of phospholipids (biochemical constituents of bacteria) as biomarkers detectable by mass spectrometry. These experiments are being done with a commercial, laboratory-sized, triple quadrupole mass spectrometer equipped for both atmospheric pressure ionization (API), including atmospheric pressure chemical ionization (APCI), and ESI (electrospray ionization). In the future, these experiments will be carried out with a Finnigan LCQ mass spectrometer, which is more modern and more compact and uses an ion trap (the mass analyzer favored by the independent Executive Panel).

Two subcontractor personnel and one government employee are working with the subgroup leader, who also collaborates (via contract) with experts in two other laboratories, Pacific Northwest Laboratory and the Beckman Research Institute, City of Hope National Medical Center, to improve sample preparation prior to injection of the sample into the pyrolysis zone. One microbiologist (a contractor) works at the Fort Detrick facilities to prepare quantities of virulent agents that are then killed and sent to the ERDEC to be used as "real" samples rather than the nontoxic surrogates.

Laser-Based Mass Spectrometry

The second subgroup's objective is to develop laser-based approaches to agent detection. Presently, MALDI (matrix-assisted laser desorption ionization) is used to assess the reproducibility of the process for detecting proteins released during the lysis of cells. Mass spectra (representing signals corresponding to the molecular weights of the proteins present in the lysate) vary greatly, depending on the history of the sample (e.g., growth conditions, such as nutrient, time of growth, and pH). The spectra have been reproduced, under highly standardized conditions, only at the University of Alberta, with which this group collaborates. The experiments are carried out using various time-of-flight (TOF) mass spectrometers. The results of the MALDI approach are expected to be equivalent to those obtained with the ESI methodology using an ion-trap mass spectrometer, which was recommended by the Executive Panel.

The work of this subgroup has been severely limited by shortages in manpower because the leader spends about half of his time in another capacity and has only one co-worker (a contractor).

Direct Mass Spectral Analysis

The objective of the third subgroup is to use MALDI (and ESI in the future) to obtain mass spectrometric fingerprints of bacteria by direct mass spectral analysis with the aim of identifying selected materials on the DOD threat list. A library of MALDI mass spectra has been generated from approximately 100 different pathogens, nonpathogens, and pure, known proteins. The spectrum of an unknown material is matched to the library using an algorithm developed under contract at the University of Washington, Seattle. In January 1998, this strategy was tested in blind studies at Dugway Proving Ground. For this purpose, the laboratory MALDI mass spectrometer was shipped from the ERDEC to Dugway to be used on site by the subgroup leader and the one (and only) co-worker, a contractor who began work about December 1, 1997. Because of the time consumed in the preparation for and participation in these tests, the subgroup leader had no time in 1997 to compile and evaluate the results of the work done in 1996.

The 1997–1998 Dugway tests involved the MALDI methodology with a TOF mass spectrometer rather than the ESI ion-trap methodology recommended by the Executive Panel. It appears to the committee that the older technology was used according to an established plan, without regard for the recommendations that the methodology be changed. The committee feels that both time and money would have been saved by canceling the test. Furthermore, if the 1997/98 tests are handled the way the 1996 tests were, it will be some time before the results are released.

This subgroup is very well equipped, in fact, it is overequipped. The group now works with ESI on a commercial spectrometer (Finnigan LCQ), which is being modified for very small samples and low volumes of liquid. But overall, there are more mass spectrometers than can be used by the two full-time employees.

Observations

The second and third subgroups have been working on the same basic approach, namely the detection of certain micro-organisms by MALDI mass spectrometry to identify characteristic proteins. However, because all or most of the microbial samples used by the third subgroup were single runs taken from petri dish cultures, the cells that were analyzed had probably all shifted to stationary-phase physiology. The pattern of protein expression was, therefore, probably quite different from the pattern in cells that would be produced by an adversary for battlefield delivery. The committee believes this subgroup should refocus its attention on generating extracts from cells grown under conditions likely to be used in the production of biological warfare agents. During the course of this review, the committee learned that another subgroup in the mass spectrometry group was already aware of the importance of the variability of protein expression, but because of the lack of information exchange and discussion, this important information was not available to the other subgroups.

One senior member of the mass spectrometry group was concerned that the recommendations of the Executive Panel might be adopted before technologies other than mass spectrometry had been considered. The committee notes that there are other possible methodologies, including immunological methods, polymerase chain reaction (PCR), and other antibody/antigen-based systems.

The sensitivity goals for any detection system were set by the Operational Requirements Document (ORD) at 100 cells/ml of water in the accumulator of the air sampling device (1,000 L of air/min). None of the three subgroups has paid much attention to the detection limit in terms of the number of detectable cells. The samples used are 2 to 4 orders of magnitude more concentrated than the ORD specifies. Nobody in the mass spectrometry group could provide the committee with the scientific basis for using 100 cells/ml or knew whether the biomarkers present in 100 cells would be sufficient to produce a reliable signal in any system based on mass spectrometry.

Another possible approach to the detection-identification problem is the German mass spectrometer for detecting chemical and biological warfare agents that was used on a limited basis during the Gulf War. The committee learned that this system all but failed the 1996 Dugway field tests. It was only able to differentiate proteins from nonproteins and spores from nonspores. An improved version of the instrument has been developed by Bruker-Franzen (Germany), but because of its shortcomings, Oak Ridge National Laboratory has been told to "take it apart and fix what is wrong." The committee feels that, even though the German mass spectrometer did not work well in the 1996 Dugway field tests, the mass spectrometry group should monitor the progress of Oak Ridge National Laboratory's efforts. The lessons learned by Oak Ridge might very well help the RTD mass spectrometry group progress with the development of a battlefield detector by the year 2000.

The committee is concerned that the recommendations of the Executive Panel have not been considered by the mass spectrometry group in setting its priorities. By the committee's February meeting, seven months had elapsed, and this information had still not been passed on beyond the team leader. Thus, it will be a long time before the panel's recommendations will be known to the rest of the DOD community, which should have an opportunity to comment on the recommendations and work toward the same goals. The committee also believes that the recommendations of the Executive Panel should be circulated outside the RTD for comment. This can be accomplished by writing to colleagues in respected mass spectrometry laboratories, convening a discussion group of knowledgeable individuals, or disseminating the Executive Panel's recommendation by any other means that would open them to discussion and examination. In the meantime, the committee believes other technologies that could detect agents better than mass spectrometry should be investigated. If these other technologies are found to be superior to mass spectrometry, the RTD should consider reducing or eliminating the mass spectrometry program. If these technologies are not found to be superior and the Executive Panel's recommendations are validated, the mass spectrometry group should reevaluate its priorities.

PROGRAM REVIEW

The committee reviewed responses to questionnaires and conducted interviews with members of the mass spectrometry group. Based on the written responses to the questionnaires, the committee learned that RTD employees and contractors held very different views. For the interviews, the committee was divided into groups by review category, and the interviewees moved from group to group. The interviewees were frank and open, and their responses were consistent.

General Findings

The mass spectrometry group has the potential to make important contributions to the ERDEC's mission. The group has good instrumentation, and some imaginative members. Nevertheless, a reorganization of the program and the nurturing of a spirit of teamwork could have a positive effect on its *esprit de corps* and productivity. The following sections contain highlights of the committee's assessment. Detailed descriptions of all characteristics can be found in Appendix A.

Strategic Vision Category

Characteristics

- Mission and vision
- Strategic planning
- Stakeholder buy-in
- Leadership

Serious deficiencies were found in the Strategic Vision Category, especially the lack of management direction, or leadership. The management should coordinate the efforts of the subgroups toward the achievement of goals and the mission. At this point, it may be instructive to define the terms "mission" and "goals," as used by the committee. The mission is the long-term reason for the existence of the group. It seldom changes and is used to orient the work of all members of the group. Goals are short-term milestones toward fulfilling the mission. Based on the committee's interviews, the mission is to "improv[e] the methodology for chemical-biological point detection."

The mass spectrometry group has a number of goals, one of which is to develop the battlefield chemical biological mass spectrometry detector. Individual projects relate to this near-term goal of developing a battlefield detector, but are not coordinated from above. In general, the committee found that the PIs are pursuing their research in keeping with their individual concepts of the mission.

There were conflicting views as to the cause of this disorganization. Some interviewees told the committee that the group leadership was responsible because it did not have the expertise to understand the technical details of the scientific work. (The committee believes that, although the PIs must have expertise in mass spectrometry, the group leader does not need the same expertise. However, he should be knowledgeable in mass spectrometry, technology management, and strategic planning). Other interviewees were of the opinion that the PIs have "world-class" reputations and should not be micromanaged. In the judgment of the committee's technology experts, the PIs are competent and knowledgeable but not world-class experts, which the committee defines as individuals who are known and respected throughout the world for major accomplishments in their fields. The committee concluded that neither opinion was correct.

The mass spectrometry group should be mission driven, and all of its work should be focused on achieving its goals by the shortest and most effective route. Some changes that might improve the situation are: coordination of the work of the subgroups to achieve the goals of the group; identification of customers and an understanding of their needs; implementation of better project management, perhaps stage-gate management, if applicable (Cohen et al., 1998). Stage-gate management prohibits a project from moving forward (passing through a gate) until a prespecified list of requirements has been satisfied. This management technique requires that a design be carefully planned up-front and then frozen, reducing the chances of costly changes part way through the project.

Value Creation Category

Characteristics

- Portfolio selection
- Cycle time and responsiveness
- Value of work in progress

Although CBDCOM and ERDEC projects are focused mostly on the development of equipment and technologies, the mass spectrometry program also includes basic research. The committee's major concern in this category was the lack of focus of the overall portfolio of projects. The first priority of the PIs is that the work be interesting to them and that funds be available. The second priority is that the work further the broad mission of the group. This order of priorities does not usually contribute to the effective management of an overall program.

During the interviews, not all members of the mass spectrometry group were able to state their mission. The committee recognizes that the group is not a formal, separate team, but is part of the Chemical Biological Point Detection Team and, therefore, may not have a formal mission statement. Nevertheless, the members of the group must know their mission. A prominent example of the lack of focus is that the group is pursuing both long-term basic research and applied research, which require different training, different associations with both peers and customers, and sometimes different equipment and facilities. The committee believes that the mixture of long-term basic research and applied research reflects a lack of focus, which could be improved by management using funding decisions to focus research projects on the mission.

Customer Focus Category

Characteristics

- Customer
- Customer satisfaction
- Customer involvement
- Market diversification

Although the mass spectrometry program is making progress in focusing on its customer and the customer's needs, not all members of the group could even identify the customer. Nor has the group established a process for measuring customer satisfaction, which makes it difficult, if not impossible, to assess customer involvement and satisfaction. Generally, the scientists assured the committee that their customers were satisfied, and they cited the continued funding of their projects as proof. Nevertheless, the group seems to be reluctant, or very slow, to adopt ESI as the preferred ionization method and the quadrupole ion trap as the analyzer, even though the Executive Panel gave these two items a high priority. The committee observed that the PIs were equipped with a number of MALDI instruments but not ESI. Their work is thus involved in the former technology (except for one PI who uses pyrolysis GC-MS), and changing to ESI would require a major change in their experiments as well as new equipment. Only one PI has, in the meantime, acquired an ESI-ion trap (Finnigan LCQ) and is adapting it to work with very small sample volumes.

The Assessment Model (Appendix A) suggests that market diversification is beneficial to a laboratory. In general, such diversification promotes funding stability and long-term growth. The committee did not hear of any attempt by the group to diversify its customer base to include other military or national laboratories. The committee sees several potential customers for the mass spectrometry group, both internal and external. Even though the "end users," or soldiers, may not see the results of basic research for many years, their needs must set the goals. The proxies for soldiers are developers, testers, engineers, and applied scientists who incorporate the results of basic research into their own work. The RTD management should prioritize these customers, as well as other stakeholders, such as scientific peers.

Resources and Capabilities Category

Characteristics

- Organizational culture
- Employee attitude
- People development
- Budget/funding
- RD&E capabilities, skills, and talents
- Intellectual property
- Technology sourcing
- Information technology
- Facilities and infrastructure

Based on information received during the interviews, the committee was disturbed by the lack of interaction among the mass spectrometry subgroups, which have adopted an attitude of protecting information from their colleagues. The committee found that many members of the mass spectrometry group have an independent, competitive attitude that stresses competition rather than a team-oriented, cooperative attitude. This has had a negative impact on the internal sharing of information and has been a barrier to productive research.

Some interviewees indicated that there are not enough qualified people to operate the state-of-the-art equipment. For example, the committee learned that a tandem mass spectrometer that cost at least $1.2 million has not been used for about 18 months. One solution would be to increase the authorization or funding to hire or train personnel. Another solution would be to increase the use of the equipment by outside groups, either government or nongovernment. In any case, the fact that the instruments are underused suggests that the procedures for acquiring appropriate skills need urgent attention.

During the second set of interviews, the committee detected a problem with high turnover but was not able to pursue this issue in sufficient detail to determine the cause or to suggest a possible remedy. However, the committee suggests that ERDEC and the RTD management assess the extent of the problem and develop ways to resolve it.

Quality Focus Category

Characteristics

- Capacity for breakthroughs
- Continuous improvement
- Teams
- Evaluation and rewards
- Project management
- Regulatory compliance
- Commitment to quality
- Process management
- Metrics
- Safety
- Knowledge and learning

The committee could find no evidence that any performance metrics (see Table A-5) were being used, which suggests that the group is not totally committed to quality. A commitment to quality requires breaking down an operation into its processes (e.g., recruiting, training, planning, researching, observing, recording, etc.) and determining the steps in the process that add value, the steps that can be eliminated, and the issues that should be addressed. The committee found little evidence of this formal approach at the group or subgroup level.

The lack of attention to detail is reflected in the lack of attention to process management or project management. Although a group this small cannot, by itself, implement a Baldrige National Quality Award[1] or ISO 9000[2] program, high quality teams of this size are common. As some management experts have stated, in reference to project-oriented companies, "it is most effective to keep the groups small, four to fifteen members; about eight members is optimum" (Stephanou and Obradovitch, 1985, p. 329). A

[1] The Baldrige National Quality Award was established by Congress in 1987 to recognize U.S. companies for their achievements and to raise awareness of the importance of quality and performance as competitive advantages.

[2] The ISO 9000 series of International Standards for quality management and quality assurance has been adopted in more than 90 countries and is being implemented by thousands of manufacturing and service organizations, both public and private.

stronger commitment to quality at the laboratory level might require the involvement of the RTD senior management, which has the responsibility for overall quality. (This subject is discussed further in Chapter 4).

The performance of the mass spectrometry group could be improved if a formalized project management process were implemented. The same principles of project management used to build a plant or manufacture a product can be applied to basic research projects. One example of project management at the basic research level (at Exxon) is described in an article by Cohen, et alia (1998). "A critical requirement for a productive centralized basic research unit is the achievement of seamless interfaces between it and decentralized functional laboratories" (p. 34). The authors state that, "The stage-gate system . . . provides direction for the success of science-based technology" (p. 37). Achieving a breakthrough requires teamwork, skill, adequate funding, and strong leadership. Personnel in the best laboratories are able to enumerate the breakthroughs they have made in the last five to ten years.

Breakthroughs need not be limited to basic research. The American Heritage Dictionary (3d ed.) defines a "breakthrough" as "1. An act of overcoming or penetrating an obstacle or restriction. 2. A major success that permits further progress, as in technology." The ERDEC has recognized the importance of breakthroughs in its criteria for the 1994 Department of the Army Research and Development Organization and Excellence Awards, in which breakthroughs are placed on the same level as "customer satisfaction," "meeting assigned objectives," "technology product transitions," and "leveraging of industry, academia and services/agencies" (ERDEC, 1994). Clearly breakthroughs are desirable to the Army whether the group is doing basic or applied research. (For a description of a breakthrough, see "Capacity for Breakthroughs" under the Quality Focus Category, Table A-5.) The committee found very few examples of breakthroughs in the mass spectrometry program.

Evaluations and rewards was an emotional subject for the mass spectrometry group. Although numerous rewards were available, some employees stated that they did not understand the process by which rewards were given or the linkage between performance and rewards. Some interviewees also complained that financial rewards were meager. The financial rewards available for the mass spectrometry group, as reported by the interviewees, appear to be too small to have much effect in any case. Some of the interviewees felt that recognition by a respected person or organization would be more meaningful than a meager financial reward. On a more basic level, the committee is not convinced that financial rewards motivate quality work.

In many cases, attendance at a professional meeting has become a substitute for a financial reward. However, some interviewees suggested that attendance at meetings was not always granted for the best work (e.g., a person in a senior position may attend a meeting rather than a person whose work is more clearly related to the subject). Some interviewees felt that excessive attendance by seniors had interfered with work on some projects. This problem reflects on the RTD's procedures for retaining and developing research and engineering capabilities, skills, and talents.

Most members of the mass spectrometry group felt that safety was not an issue because they work with instruments and computers and are not exposed to hazardous environments. They believe they are exposed to the same dangers as secretaries. When the committee suggested the possibility of repetitive operations disorders, the interviewees responded that these hazards were not worth evaluating. Because of the absence of safety records, the committee could not evaluate the frequency of these disorders, which may occur but may not be recognized.

The three mass spectrometry subgroups do not willingly exchange scientific information because they consider each other competitors. Biweekly group meetings are largely concerned with management and funding issues rather than the exchange of results or scientific ideas. Also, annual or biannual program reviews with upper management are considered to be superficial and inadequate. This problem reflects on ERDEC's procedures to develop research and engineering capabilities, skills and talents. The prevalent culture, which discourages interaction among the subgroups, must be changed by subgroup, team, and, if necessary, RTD management. Informal meetings should be encouraged as forums for the exchange of information.

OPPORTUNITIES FOR REENGINEERING

Based on the first interview session, the committee found that the mass spectrometry group could make improvements in all five categories. The committee then developed a priority index (see Table 2–1) to identify the characteristics that need the most improvement. The committee's most serious concern is the lack of metrics. Without metrics, progress cannot be measured, milestones cannot be defined, budgets and schedules cannot be controlled, and the risk of failure is increased. Although the use of metrics is only one part of quality management. it is important for quantifying customers' needs and ensuring that they are satisfied. For example, a customer describes a requirement for the development of a

TABLE 2-1 Programmatic Review of the Mass Spectrometry Group

	Maturity Stage (4 = High)						Importance (4 = High)				Priority Index[a]
	0	**1**	**2**	**3**	**4**	*****	**1**	**2**	**3**	**4**	
Strategic Vision											
Mission and vision			2					2			4
Strategic planning			2						3		6
Stakeholder buy-in		1							3		9
Leadership		1								4	12
Value Creation											
Portfolio selection			2					2			4
Cycle time and responsiveness		1						2			6
Value of work in progress			2					2			4
Customer Focus											
Customer			2							4	8
Customer satisfaction		1							3		9
Customer involvement			2						3		6
Market diversification		1							3		9
Resources and Capabilities											
Organizational culture		1								4	12
Employee attitude			2							4	8
People development			2					2			4
Budget/funding				3					3		3
RD&E capabilities, skills, talents			2							4	8
Intellectual property		1					1				3
Technology sourcing			2					2			4
Information technology			2					2			4
Facilities and infrastructure			2						3		6
Quality Focus											
Capacity for breakthroughs			2							4	8
Continuous improvement		1							3		9
Teams				3					3		3
Evaluations and rewards			2					2			4
Project management		1							3		9
Regulatory compliance			2					2			4
Commitment to quality		1								4	12
Process management		1						2			6
Metrics[b]	0								3		12
Safety				3						4	4
Knowledge and learning		1							3		9

[a]The Priority Index, (4 – maturity stage) x importance, shows the relative need for corrective action. The higher the number, the more urgent the need.

[b]No evidence of the use of metrics was found.

system that can act in certain ways under certain circumstances. The PI then develops detailed metrics for measuring progress towards satisfying this requirement.

The lack of commitment to quality management filters down through the organization and has a direct impact on the performance environment of the groups and subgroups. According to the interviewees, the organization as a whole does not use performance metrics.

RTD management should establish and implement a strategy for focusing on quality management (see discussion in Chapter 4). RTD management should set an example of long-term cultural change, frequent follow-on help sessions to reinforce the serious intent of management to "stay the course," and other mechanisms that demonstrate a determination to change the institutional culture. (Daft, 1998). The ERDEC management could learn from the experience of other government agencies and the private institutions that have overcome destructive competitive atmospheres and established cooperative atmospheres. Successful institutions could also provide performance metrics, effective means for continuously improving processes. Finally, by observing other organizations, especially organizations similar to the mass spectrometry group, the RTD management might be able to find extremely good processes by which to benchmark their own progress.

STAGES OF MATURITY AND PRIORITY INDICES

The committee developed a priority index, based on maturity stage and importance, that identifies areas that need the most attention. The Priority Index column of Table 2-1 shows the characteristics that require immediate attention. The higher the priority index, the greater the need for attention. Expressed as an equation, Priority Index = (4-maturity) x importance. For example, in Table 2-1, the maturity stage of the second characteristic under Strategic Vision, strategic planning, is 2. The importance is 3. The priority index for strategic planning is therefore (4-2) x 3 = 6.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Conclusion 1. The subgroups of the mass spectrometry group were not able to identify their customers or their customers' needs.

Conclusion 2. The work of the mass spectrometry group is not cohesively focused on its mission.

Conclusion 3. The three mass spectrometry subgroups work in relative isolation from each other and do not regularly share ideas or results.

Conclusion 4. The mass spectrometry group does not make full use of its sophisticated, expensive equipment.

Conclusion 5. The mass spectrometry group does not use performance metrics to evaluate continuous improvement.

Conclusion 6. The priorities and recommendations of the Executive Panel have not been followed.

Conclusion 7. Mass spectrometry may not be the best system for detecting and identifying biological agents.

Recommendations

Recommendation 1. The leadership of the mass spectrometry group should focus the work of the overall program by defining the mission and goals, setting scientific priorities, ending internal competition, and promoting cooperation, including data sharing.

Recommendation 2. The management of the Research and Technology Directorate should bring all three subgroups of the mass spectrometry group together into one laboratory complex.

Recommendation 3. As soon as possible, the senior management of the Research and Technology Directorate should evaluate, with the assistance of outside experts, the effectiveness of mass spectrometry for detecting and identifying biological agents as other approaches, such as immunological methods, polymerase chain reactions, and other antibody/antigen-based systems. In addition, senior management should seek an independent evaluation of the recommendations made by the Executive Panel.

Recommendation 4. The mass spectrometry subgroups should interact closely with other groups working with polymerase chain reactions, flow cytometry, and other immunological detection systems to compare the performance levels (e.g., analytical specificity and sensitivity) of these technologies. If mass spectrometry does not perform at an equal or higher level, the mass spectrometry group should develop a program that would meet the highest performance requirements. This program should then be evaluated by the management of the Research and Technology Directorate for its feasibility.

Recommendation 5. The scientific capabilities and research projects of all three mass spectrometry subgroups should be evaluated in relation to the recommendations of the Executive Panel to help management make optimum assignments. Once priorities have been established for the mass spectrometry group, tasks should be assigned to the subgroups according to their scientific capabilities.

Recommendation 6. The sophisticated, expensive equipment should be fully used.

Recommendation 7. The mass spectrometry group and management of the Research and Technology Directorate should develop and implement performance metrics to measure progress.

3

Bioremediation

DESCRIPTION

The bioremediation group is part of the Environmental Technology Team (ETT) under the Research and Technology Directorate of the ERDEC (see Figure 2-1). Like the mass spectrometry group, the bioremediation group does not have a separate leader but reports directly to the leader of the ETT. The mission of the ETT is to develop biological and/or biochemical systems for detoxifying or destroying hazardous chemicals of military significance, primarily chemical warfare agents (including their precursors and products), obsolete decontaminants (e.g., DS2), and explosives and propellants that would be encountered in the destruction of chemical munitions. Smaller programs involve the detection of biological agents and toxins. The sciences that support these programs include microbiology, biochemistry, molecular biology, and biochemical engineering. The largest current program area is the development of enzyme-based chemical and biological warfare (CBW) decontaminants. Areas of interest to the bioremediation group include: molecular modeling and microbiology to identify new enzymes that act against the nerve agent VX; the enzymatic decontamination of bacterial agents; and the hydrolysis of soil contaminants.

TECHNICAL CAPABILITIES

The bioremediation group consists of 12 people, who were working on 11 projects in fiscal year 1997 and 13 projects in fiscal year 1998, mostly in subgroups of one, two, or three, but in one case, a subgroup of six. A PI leads each subgroup. The primary projects cover pathogen detection systems, molecular modeling of agent-degrading enzymes, the biodegradation of chemical warfare materials, and the enzymatic decontamination of biological warfare agents. Most of the programs, which have been ongoing for a number of years, range in cost from $25,000 to $760,000 annually and include independent laboratory in-house research (ILIR), basic research, applied research, and customer-funded projects.

The largest current project, Enzymatic Decontamination, is in the development of a new generation of CBW decontaminants that use catalytic enzymes and, unlike current decontaminants, are nontoxic, noncorrosive, nonflammable, and environmentally safe. One area of progress has been the development of enzymes that can destroy G-agents (e.g., Soman and Sarin). Another area of focus is the development of enzymes that can destroy V-agents and mustard agents.

A smaller project, the Alternative Technologies Program, is concerned with the demilitarization of chemical weapons (CW) stockpiles. The actual demilitarization is the responsibility of a program office that reports directly to the Assistant Secretary of the Army for Research and Development. The goal of the Alternative Technologies Program is to develop biotechnological methods for destroying the CW stockpiles as an alternative to incineration. Hot water hydrolysis followed by biodegradation was successfully demonstrated for the destruction of mustard agents. This technology has been selected for use in the destruction of the 1,625 tons of mustard agent stored at Aberdeen Proving Ground in Maryland. Related projects deal with the use of biological systems to destroy hydrolyzed VX and Sarin. Although these biological systems are not as advanced, their ability to destroy these organophosphorus compounds has steadily improved. The Alternative Technologies Program is now attempting to determine whether the explosives/propellants found in CW munitions can be disposed of by similar biological means.

The objective of a third project is the biodegradation of DS2, the current decontaminant in the Army's inventory. Although DS2 is effective, it is also toxic, flammable, and highly corrosive. The Army needs to dispose of the current stockpile of 2.5 to 3 million gallons of DS2. Some of the DS2 may be sold to industry for use as a chemical feedstock (e.g., ethylene glycol monomethyl ether [EGME] and diethylenetriamine [DETA]), but much of it will require treatment and disposal. The effort, begun in 1996, to develop microbiological systems that can mineralize the organic components of DS2 has made steady progress. Initially, only the EGME was degraded, with the DETA only contributing some nitrogen (amine) for growth. Gradually, cultures were obtained that could also mineralize the DETA. The system has now reached the point where the excess nitrogen in the system is progressively converted from ammonia to nitrite to nitrogen gas. Current efforts are aimed at increasing the concentration of DS2 cultures can tolerate and optimizing the operation of the bioreactor.

The goal of the fourth project (an ILIR) is the development of genetic probes for the detection of *B. anthracis*. Its purpose is to develop strain-specific DNA probes that can discriminate between *B. anthracis* and related bacilli, such as *B. cereus* or *B. subtilis.* A variety of probes have been designed and tested this year and show very good specificity for the target organism. The probes identified in this project will be adapted for use in sensors under development by the Biodetection Program.

Members of the scientific staff consider publications to be important, but not as important as customer satisfaction and the deployment of their products. The bioremediation group believes that their products (processes, methods, and specific organisms and enzymes) are a better measure of their success and accomplishments than their basic research publications. Thus, they believe that the quality of their work should be compared to the quality of work by organizations that do applied research rather than basic research. In general, the group has a positive sense of the future of the CBDCOM, and recent employees (contract personnel) believe they have a future in the organization.

PIs conceptualize the purpose of their programs and projects on the basis of their general perception of their program mission, that is, enzymatic decontamination, demilitarization of CW stockpiles, biodegradation of DS2, and genetic probes for the detection of *B. anthracis*. Operationally, goals are based on the projects that have received Technical Base funding during the previous year. Unfortunately, because Technical Base funding is awarded through a competitive process on a yearly basis, it has been difficult to develop and manage programs to achieve specific goals—such as proving the feasibility of a given technology by a given year (e.g., a replacement for DS2 by 2001). Most of the PIs are confident that they have the intellectual and technical competence to succeed at the CBDCOM, and they rely on interactions among themselves to plan and execute projects. Nevertheless, the activities of the subgroups are not well coordinated, and none of the subgroups shows any interest in working with related RTD groups.

Some years ago, there were annual program reviews of major research and development areas, called Vertical Reviews. The current annual Technical Base program reviews do not provide an overview of the capabilities of the various research groups in the RTD. The purpose of the current reviews is to determine whether projects have met their goals for the year and whether their plans for the future are reasonable. These reviews are also used to prioritize projects so that if money is limited, the highest priority projects will be preferentially funded. Proposals for new projects are also evaluated and could "bump" ongoing projects if they are deemed to be of higher priority or to have greater potential. The committee believes that reinstituting Vertical Reviews that afford scientists an opportunity to coordinate their projects and increase their understanding of the work of other teams could greatly improve interaction among the RTD groups and might also increase productivity.

The individuals interviewed were well aware that technologies for the development of new biological/threat agents and for countermeasures are changing rapidly. Nevertheless, a hiring freeze has prevented management from bringing in new permanent staff members with new capabilities. The committee believes that management could minimize the effects of the freeze by initiating a continuing education program so that "older" staff members can upgrade their skills.

Even though project leaders are proud of their success in developing new technologies that could have practical military applications, (e.g., the destruction of agent breakdown products), they do not feel that it is their responsibility to promote the technology or to work with other groups, such as the engineering group, to ensure that the technology is appropriately implemented. In other words, they subscribe to the school of technology transfer, in which an organization takes no further interest after passing its product to the next group in line.

Most members of the subgroups in the bioremediation group told the committee that they do not have enough technical, clerical, or administrative support to carry out their projects. Because of this personnel shortage, Ph.D.s have to do routine analyses and media preparations. PIs reported that they had no trouble getting equipment for their projects, but the equipment often remains idle because of the shortage of qualified operators. The committee believes that the bioremediation group as a whole would be more efficient with a more balanced ratio of technicians to Ph.D.s.

The members of the bioremediation group do not have a clear understanding of how the review panel for Technical Base funding works. Interviewees reported that they are not informed why their proposals are funded or not. This lack of communication about the review process has led to the perception that the review panel is not competent to understand the technical details of proposals and cannot justify its decisions. The interviewees consider the whole review and decision process to be highly political and suspect that another group is being given preferential treatment. They are convinced that securing funds depends on submitting proposals that are only two to five pages long, too short to present a credible case for their research projects.

The preoccupation with funding, especially the continuity of funding, limits productivity. Even if funding is approved for a three-year period, the funds can be reallocated to another group after one year. Thus, PIs behave as if they have only one-year funding and spend a good deal of time writing unnecessary proposals. Subgroups could seek outside funding, but they anticipate that the ERDEC management would cancel some of their Technical Base funding if outside funding were secured. Outside funding also tends to be short term and requires more proposal writing. However, in the committee's view, the number of proposals is less than the number that would be required for a comparable research organization in the private sector.

In fact, concerns about funding have led the bioremediation group to solicit projects from other government agencies and industry, which interferes with the fulfillment of their central mission. These additional projects, which are often underfunded, have diverted efforts from in-house projects.

According to the information provided to the committee, only three of the 12 PIs are involved in more than two projects. Thus, most of them are involved in fewer projects than researchers in other active research/development organizations. Complaints that PIs are being diverted from their main focus by external "customers" is belied by the fact that only 20 percent of their funding comes from external customers.

The PIs appear to have healthy working relationships with the academic community in the immediate area. Contacts have been established by their attendance at national meetings of major technical societies, such as the American Chemical Society and the American Society of Microbiology. The interviewees informed the committee that the RTD does not invite external experts to present their work to PIs. Members of the bioremediation group also reported that the intelligence community does not keep them informed of biological and chemical agents being developed by foreign countries. Nor are PIs briefed by RTD management about potential biological threats. Therefore, the PIs do not have sufficient information to anticipate future army needs and tailor their proposals accordingly.

The interviewees were not aware of any administrative incentives that would reward productive researchers. They consider the periodic, required productivity reviews a waste of time because there are no perquisites (e.g., salary raises, bonuses, or resource allocations) to reward exemplary contributions to the organization.

PROGRAM REVIEW

The bioremediation group was considered as part of the RTD as a whole. The committee attempted to separate the responsibilities of senior RTD management that affect the performance of the bioremediation group from factors that are within the control of this group. The interviewees were open and frank in talking with the committee. The written responses were less helpful, however, because of the limited number of responses and the lack of clear, direct answers to the questions.

Strategic Vision, Value Creation, and Customer Focus Categories

Characteristics		
Strategic Vision	**Value Creation**	**Customer Focus**
• Mission and vision	• Portfolio selection	• Customer
• Strategic planning	• Cycle time and responsiveness	• Customer satisfaction
• Stakeholder buy-in	• Value of work in progress	• Customer involvement
• Leadership		• Market diversification

The levels of maturity for the bioremediation group are high for most of the characteristics in these three categories. The group has a clear understanding of its mission, and the technical programs and deployment of resources are in keeping with the mission and vision of the group. The plan of the group is also consistent with the thrust of the RTD as a whole.

The quality of leadership is high. The information flows in both directions between management and staff, and an air of excitement pervades the laboratory. Risk-taking is encouraged, and leads are quickly pursued. The leadership has excellent technical knowledge, which the team perceives as an asset because the leadership is able to explain the importance of each project to more senior management. The leadership works to generate funding and also shelters the team from low priority issues that could interfere with its work.

Although the group does not have formal measurements for assessing customer satisfaction, customers appear to be satisfied. Internal customers are involved in setting work objectives, and the group's products serve a broad array of clients, including universities and private industry. On joint programs, the group has been assigned as the DOD lead.

The committee's greatest area of concern is the process of portfolio selection. The overall program appears to be technology driven rather than mission driven. The interviewees repeatedly described focusing first on what they enjoyed doing and then selling their ideas to funding organizations.

During Fiscal Year 1997 (FY), there were 11 bioremediation projects costing $1.958 million; four of those, costing $485,000 were customer-driven projects (36 percent by number and 24 percent by cost). Although the focus on customer needs was a relatively new phenomenon, the bioremediation group attempts to respond quickly to customers' needs, and customers appear to appreciate these efforts to satisfy them.

Resources and Capabilities Category

Characteristics

- Organizational culture
- Employee attitude
- People development
- Budget/funding
- RD&E capabilities, skills, and talents
- Intellectual property
- Technology sourcing
- Information technology
- Facilities and infrastructure

The bioremediation group scored well in most of the characteristics of this category. The committee was most impressed by the organizational culture and employee attitude. The *esprit de corps* of the group is shared by employees and contractors, and the only barriers to the sharing of information are the necessary limitations on sharing financial information with contractors. All members of the group are valued for their unique skills, and staff members are willing to make extra efforts for the team to succeed. The committee found that the rapport among PIs is warm and respectful and that every member of the group takes full responsibility for his or her growth, both technically and personally. The issue of funding is important to everyone, but the group management seems to be adept at securing support, even though a few projects are underfunded. Technical experts on the committee concluded that the bioremediation group's technical capabilities are sufficient to meet customer needs and that state-of-the-art techniques are understood and applied.

One area that could be improved, however, is technology outsourcing, which is research funded by RTD and performed in an outside laboratory but monitored by the bioremediation group. Currently, the group does not have a formal process for selecting outsourcing projects. The CSC felt that the work of the group could be leveraged by including outside experts who are familiar with the skills, talents and facilities of other laboratories in outsourcing decisions. The committee believes that this change would enhance the RTD's acquisition of research engineering capabilities, skills, and talents.

The committee judged that the level of maturity of information technology is high. Computers are widely and appropriately used, employees are linked electronically, networking is encouraged, equipment is current, and in-house training is available. To increase efficiency, information technology should be used as much as possible.

The interviewees consider their research equipment and facilities to be modern and well maintained, which is readily apparent in the new facilities the team occupies.

Quality Focus Category

Characteristics

- Capacity for breakthroughs
- Continuous improvement
- Teams
- Evaluation and rewards
- Project management
- Regulatory compliance
- Commitment to quality
- Process management
- Metrics
- Safety
- Knowledge and learning

In the committee's opinion, continuous improvement is not a focus area of the bioremediation group, which might reflect the need for RTD management to increase its commitment to quality. A stronger commitment to quality may be difficult for the bioremediation group to achieve on its own. The group does not use metrics to assess improvements. The committee believes, however, that the group would benefit from more formal project management, even of basic research projects. Considering the great variety of work being done by the bioremediation group, the committee was surprised at the lack of internal teamwork to improve processes and increase efficiency.

The bioremediation group appears to be proficient in most of the other characteristics in this category. For example, the interviewees were able to describe breakthroughs, which indicates that the concept is understood and that breakthroughs are made fairly often. However, safety is a serious concern in the bioremediation group. Members of the group agree that management is truly concerned about safety and does "walk the talk." All members of the group are well trained and understand safety issues. However, the committee saw no indication that safety issues are being addressed strategically, and safety statistics are not widely disseminated. In all other areas, the bioremediation group seems to comply with regulatory safety requirements.

The rapport among members of the bioremediation group facilitates the sharing of information among colleagues. Although some interviewees were skeptical about the connection between performance and rewards, they all seemed to have accepted the situation.

OPPORTUNITIES FOR REENGINEERING

The Priority Index in Table 3-1 indicates the characteristics in the assessment model that require the most attention. Although the bioremediation group is clearly effective in many ways, a stronger commitment to quality would have a cascading effect on the entire group, especially in the area of continuous improvement. This commitment to quality would require a process perspective and better project management. Although the bioremediation group may not be able to focus more on quality without the support of RTD management, they could take a step in that direction by formalizing their project management.

STAGES OF MATURITY AND PRIORITY INDICES

Based on the descriptions in Appendix A, the committee assigned a stage of maturity to each characteristic under each category. A summary of the

TABLE 3-1 Programmatic Review of the Bioremediation Group

	Maturity Stage 4 = High					Importance 4 = High				Priority Index[a]
	0	1	2	3	4	1	2	3	4	
Strategic Vision										
Mission and vision					4		2			0
Strategic planning				3				3		3
Stakeholder buy-in				3				3		3
Leadership					4				4	0
Value Creation										
Portfolio selection				3			2			2
Cycle time and responsiveness				3			2			2
Value of work in progress				3			2			2
Customer Focus										
Customer					4				4	0
Customer satisfaction		1						3		9
Customer involvement				3				3		3
Market diversification					4			3		0
Resources and Capabilities										
Organizational culture				3					4	4
Employee attitude					4				4	0
People development			2				2			4
Budget/funding				3				3		3
RD&E capabilities, skills, talents				3					4	4
Intellectual property			2			1				2
Technology sourcing		1					2			6
Information technology			2				2			4
Facilities and infrastructure			2					3		6
Quality Focus										
Capacity for breakthroughs				3					4	4
Continuous improvement		1						3		9
Teams			2					3		6
Evaluations and rewards			2				2			4
Project management		1						3		9
Regulatory compliance				3			2			2
Commitment to quality		1							4	12
Process management			2				2			4
Metrics[b]	0							3		12
Safety				3					4	4
Knowledge and learning				3				3		3

[a] Priority Index = (4 – Maturity Stage) x Importance.
[b] No evidence of the use of metrics was found.

committee's findings appears in Table 3-1. The importance assigned to each characteristic was determined by the expert opinion of the committee. The Priority Index, (4 — maturity stage) x importance, indicates the priority of each characteristic. The higher the priority index, the greater the need for attention.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Conclusion 1. The quality of leadership in the bioremediation group is high. Information flows in both directions between management and staff, and an air of excitement pervades the laboratory. *Esprit de corps* is shared by both employees and contractors.

Conclusion 2. Although the portfolio seems to meet the strategic goals of the group, the overall program appears to be technology driven rather than mission driven.

Conclusion 3. The bioremediation group does not have a formal process for selecting research to be outsourced (i.e., funded at a university, other government laboratory, or corporate laboratory) or established criteria for making outsourcing decisions.

Conclusion 4. Project management, including commitment to quality and metrics, could be greatly improved. For example, an adaptation of the stage-gate model might be used.

Conclusion 5. The bioremediation group does not have opportunities to work with related groups in the Edgewood Research, Development and Engineering Center.

Conclusion 6. The bioremediation group is given little or no feedback on the reasons technical proposals are funded or rejected.

Conclusion 7. The bioremediation group is not kept up to date on intelligence estimates of biological and chemical agents being developed by potentially threatening groups and countries. This lack of information interferes with the selection of mission-oriented projects.

Recommendations

Recommendation 1. The portfolio of the bioremediation group should be linked to the larger mission of the organization. This can be facilitated by frequent intelligence briefings on biological and chemical agents that are being developed or are already in the arsenals of foreign countries.

Recommendation 2. The bioremediation group should establish a more formal process for making decisions on outsourcing and for managing outsourced projects.

Recommendation 3. The bioremediation group should establish a formal project management process to facilitate learning and improve efficiency.

Recommendation 4. Management should internally publish all funded proposals and critiques and should provide principal investigators with critiques of unfunded proposals.

Recommendation 5. The leadership of the Research and Technology Directorate should use annual Technology Base reviews for sharing information among all technology teams.

4

Management

GENERAL CONTEXT

In the Statement of Task for this study, the committee was asked to review the processes used by two representative programs in the RTD to move basic research results and technology through development. To fulfill this request, the committee necessarily focused on two relatively small parts, the mass spectrometry and bioremediation groups, of the RTD organization. Nevertheless, the processes that were reviewed are not controlled solely by these two groups. Management of the RTD exerts some influence on their ability to move research results and technology through development. Therefore, the committee also considered its findings in relation to RTD management. The committee recognizes that the findings in this report cannot be automatically extrapolated to other groups in the RTD but believes that some of the recommendations may have wider application and suggests that follow-on internal reviews of other groups be conducted.

The RTD is currently in a state of transition in terms of personnel and organizational structure. RTD management could take this opportunity to implement some of the committee's recommendations in conjunction with other changes.

Because the organization is managed so that different groups are forced to compete for resources (e.g., research dollars), the results of these reviews were to be expected. In fact, the lack of focus on the organizational mission, the absence of forward thinking, and the competitiveness between teams and team members at the time of the committee's review clearly reflect problems of organizational command and leadership. The remainder of this chapter discusses the committee's conclusions that reflect on RTD management or may be applicable to more than the two groups under review.

QUALITY MANAGEMENT AND SYSTEMS THINKING

The committee noted a gap between improvements in quality management (QM), at the working level and the perceptions of QM by upper management. Staff members who were interviewed had not incorporated the principles of QM into their jobs, and neither group had established a uniform project management process. QM processes were not documented, approaches to improvement were not consistent, and performance metrics were not used by either group. Some interviewees even seemed cynical about QM, describing it as a "management fad." In short, even though the committee had been led to believe by RTD management that training in the principles of QM had been extensive, QM principles were not being implemented at the working level. Improvements in QM at the working level may also be necessary in other RTD groups. A change in organizational culture will be necessary to change deep-seated attitudes toward QM. Examples of QM practices the committee believes should be incorporated or strengthened are: a stronger focus on satisfying the needs of the customer; emphasis on teamwork; and identification and continual improvement of processes. This cultural change will require that senior management set an example and provide long-term, consistent leadership.

The committee found that the mass spectrometry and bioremediation groups were receptive to "systems thinking," that is, a horizontal view of an organization (Rummler and Brache, 1990). Systems thinking requires elements that do not appear in traditional, vertical thinking: the customer, the product, and the flow of work. Systems thinking is based on processes that cut across functional boundaries and internal customer-supplier relationships through which products and services are produced. Most opportunities for improvement occur at the functional interfaces.

Systems thinking is consistent with the principles of QM, and most interviewees seemed willing to revisit the idea that work is a process that can be continuously improved. The committee believes that ERDEC management would benefit considerably from training the mass spectrometry and bioremediation groups, as well as other groups in the RTD, in systems thinking. Training would be based on an analysis of the work flow for RTD's key processes.

BALANCING PROJECT PORTFOLIOS

One problem common to both the mass spectrometry and bioremediation groups was that their portfolios of projects were largely accumulations of unrelated projects rather than projects that would meet strategic objectives. This bottoms-up approach was confirmed during interviews with RTD management and staff, who indicated that this was an effective approach in the battle for funding. The committee understands the RTD's reasoning but believes that a more systematic approach would be more effective.

During the second set of interviews, the committee noted in that some changes had already been made in the portfolio selection process. These changes notwithstanding, the RTD management should develop better ways of evaluating customer short-term and long-term needs and of communicating them to the mass spectrometry and bioremediation groups and, perhaps, to other groups in the RTD. Only project proposals that satisfy a customer's needs and fit into the RTD's overall strategy should be funded internally. The portfolio could then be assessed (by a technically competent panel) for gaps in meeting customer's needs, and proposals that filled the gaps could be funded.

NETWORKING AND INTERNAL SHARING OF BEST PRACTICES

The main reason for the lack of communication among the subgroups of the mass spectrometry group was a lack of trust among the PIs. If other groups in the RTD are also isolated from each other, senior management may not be putting enough emphasis on the sharing of information. The committee believes the lack of communication is really a cultural issue. The goal of RTD management, and of each group, should be to reach Maturity Stage 4, at which best practices are routinely shared, or even Maturity Stage 3, at which learning from others is encouraged.

In an article entitled *Network or Not Work*, Norling (1996) describes networking at DuPont, where individuals work together in many ways, not just on their work assignments. Thus, networking promotes socialization in the workforce. RTD management may wish to consider training the two groups that were reviewed, as well as other groups in the RTD, in networking.

CONTRACTORS AND TECHNICIANS

In the process of developing its findings about the mass spectrometry group, and at the request of contractors, the committee interviewed contractors and government employees separately, which enabled the committee to hear different perspectives. Contractors brought issues involving the

RTD's use of contractors as researchers in the laboratory to the committee's attention.

Contractors are sometimes used to provide expertise in areas where no available government personnel are available or in areas where additional expertise is needed. Sometimes the funding for contractor assistance is temporary. Under current regulations (Contracting Officer's Representative (COR) Course; Student Study Guide, 1991), it is impossible for government PIs to oversee the work of contractors on a daily or weekly basis, which makes it difficult to coordinate contractors' work with the work of government staff members. (In fact, some contractors reported feeling isolated.) This coordination problem also makes communication difficult and contributes to the overall lack of focus on the mission.

The committee found that the contracting system works better in some subgroups than in others, depending on the working relationships established in the contract and the interpretation of contractual requirements by government personnel and contractors. RTD management should look into ways to make the current contracting system more efficient. For example, it might be possible to take a strategic view of the contracting system and establish general requirements for work to be done in-house as opposed to work being contracted out (e.g., because the expertise is not available in-house). RTD management should try to develop ways, consistent with the legal requirements of government contracting, to improve the coordination of work by contractors with work by government personnel and to encourage teamwork. An on site contractor-manager might be able to facilitate coordination with contractor personnel.

The committee also received numerous complaints from interviewees about the shortage of technicians, which necessitates scientists doing routine work that cuts into the time they can spend on tasks that require their expertise. The committee suggests that RTD management review the mix of scientists and technicians and determine whether there are feasible alternatives that would make laboratories more efficient. Management might consider increasing the ratio of technicians to scientists, thereby leveraging everyone's talents.

LONG-TERM BASIC RESEARCH

Because projects are funded annually, the current procedure favors applied research over long-term basic research. Also, the time horizon of long-term basic research is less adaptable (but not entirely opposed) to scheduled milestones. One-year funding forces PIs to achieve results in a year or risk losing the next year's funding. Even when RTD funding is promised for two or three years, scientists in the mass spectrometry and bioremediation groups consider their projects to be in jeopardy every year and feel compelled to show short-term results. This atmosphere is not conducive to long-term basic research projects that may yield results only after several years of slow progress. This problem may also be interfering with long-term basic research by other RTD groups.

To alleviate this problem, RTD could sponsor more long-term basic research projects by external Army agencies, university laboratories, and industry laboratories and de-emphasize in-house, long-term basic research. This does not mean that in-house basic research should be eliminated. Some basic research will always be necessary to keep scientists current in their fields and to attract well qualified scientists. Nor does the committee mean to imply that RTD does not need the results of long-term basic research. However, the committee believes that the RTD laboratories are better suited to applied research.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions, which pertain to the two groups reviewed by the committee, may also be applicable to the RTD at large.

Conclusion 1. The corporate cultures of the mass spectrometry and bioremediation groups are not conducive to a free exchange of information among the staff.

Conclusion 2. Quality management principles have not been incorporated into the everyday operations of the mass spectrometry or bioremediation groups.

Conclusion 3. The project portfolios of the mass spectrometry and bioremediation groups are not well balanced and are not coordinated by an overall strategy.

Conclusion 4. Both contractors and government staff in the mass spectrometry and bioremediation groups are dissatisfied with their working relationships.

Conclusion 5. Because of the time limitations imposed by the annual funding mechanism and the corresponding procedure favoring the selection of applied research projects, neither the mass spectrometry nor the bioremediation group can effectively conduct long-term basic research.

Recommendations

Because these conclusions and recommendations are based on a small sample, the committee strongly suggests that the management of the Research Technology and Directorate review other groups to determine if the following recommendations are applicable to them.

Recommendation 1. Senior management should ensure that cultural changes are made that support quality management.

Recommendation 2. Senior management should establish a strategy, set goals, and define the mission for all of the laboratories. Coordinated portfolios of projects should be based on the needs of the customer, the overall strategy, and the mission of the Research and Technology Directorate, as well as on the resources and capabilities available both in-house and from outside contractors.

Recommendation 3. Management should encourage a spirit of teamwork between contractors and government staff; investigate types of contracts that allow better day-to-day management of contractors on site; ensure that both government staff and contractors are completely familiar with the rules under which they both must work; and eliminate unnecessary obstacles, perceived or actual, to the contractors doing their jobs.

Recommendation 4. Senior management should consider hiring more technicians to leverage scientists' and technicians' singular capabilities.

Recommendation 5. The Research and Technology Directorate should de-emphasize in-house, long-term, basic research and should use these funds to sponsor research with universities or transfer projects to external Army agencies that are more clearly suited to long-term basic research. The organization could then focus on practical applications of new technologies. (This recommendation may not be applicable to all groups but should be considered in future evaluations of the organization.)

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Appendices

Appendix A

Assessment Model

TABLE A-1 Customer Focus Category

Characteristics	Performance Level	Descriptions
Customer	Stage 1	The concept is not understood.
	Stage 2	The focus is on the internal customer; attempts are made to align R&D with the needs of the internal customer.
	Stage 3	The focus is on the external customer; the external customers' needs are determined by direct contact with scientists; the objective is to "give them what they want"; Quality Functional Deployment is used to identify customer needs.
	Stage 4	The focus extends to the soldier; R&D people spend time in the field to learn about the soldier's business; the objective is to "give them what they need."
Customer Satisfaction	Stage 1	Customer is dissatisfied with the strategy used to develop the product or service; appropriateness of the technological solutions; fulfillment of the operational capability requirements; technical capability, quality, and performance of the service or product; product cycle time and delivery time of the first equipped unit; technical support for fielded products developed at the RD&E organization; technical capabilities of the product or the service of the organization.
	Stage 2	Customer is satisfied with the items listed in Stage 1.
	Stage 3	Customer is very satisfied with the items listed in Stage 1.
	Stage 4	Customer is delighted with the items listed in Stage 1.

TABLE A-1 Customer Focus Category (continued)

Characteristics	Performance Level	Descriptions
Customer Involvement	Stage 1	Neither internal nor external customers are involved in program planning, evaluation, or early "results" (prototype) testing.
	Stage 2	Internal or external customers are sometimes consulted on various aspects of the research program or are involved primarily in program reviews.
	Stage 3	Internal customers are involved from time to time in setting program objectives and following progress; there are opportunities for customer feedback.
	Stage 4	Customers feel completely involved, almost like partners; customers feel they can and do have a major impact in the life-cycle development of the product or service.
Market Diversification	Stage 1	Although diversification is an aspect of strategic and business plans, senior management has not effectively broadened the customer-base for products that are developed only for the Army; few joint service RD&E programs are in place.
	Stage 2	RD&E programs provide products for the Army and the other uniformed services; the organization provides products to other federal agencies; some of the budget is devoted to developing partnerships with industry and academia.
	Stage 3	The organization is assigned DoD lead on joint programs; a significant amount of the budget is devoted to developing partnerships with industry and academia; research partnerships yield products that fulfill military needs and fill a void in the needs of other federal agencies.
	Stage 4	The organization's products serve a wide range of customers, including DoD, other U.S. government organizations, and global allies of the United States; much technology is transferred between the organization and the private sector; industry and academic partnerships result in the rapid transfer of technology between the organization and its partners; high quality products are developed, manufactured, and distributed to global customers.

TABLE A-2 Resources and Capabilities Category

Characteristics	Performance Level	Descriptions
Organizational Culture	Stage 1	People are considered as statistics; there is a clear hierarchy depending on grade level; there is a need-to-know attitude.
	Stage 2	People are valued but are perceived to be interchangeable; management makes some effort to be seen by the workers; high level information is shared with employees.
	Stage 3	People are valued for their unique skills; grade level is no barrier to communication; all information except the most confidential information is available to the whole staff.
	Stage 4	People are viewed as valued assets and are managed strategically; managers are trained in behavior modification to optimize their dealings with employees; management performance rewards includes rewards for developing people and communicating with employees.
Employee Attitude	Stage 1	The prevailing attitude is "all for one, me."
	Stage 2	Employees are willing to work hard for 40 hours/week; focus is on entitlements; some attempts are made to assess employee satisfaction.
	Stage 3	Employees are anxious for the organization to succeed; employees are willing to make extra efforts to get work done; employees are willing to work on committees, represent the organization at professional societies, and travel on their own time; a formalized employee satisfaction process is in place but actions for improvement do not appear to be linked to the findings.
	Stage 4	The concept of "technical vitality" is operative; individuals take responsibility for their own personal and professional growth; focus is on job satisfaction; a formalized employee satisfaction process is in place and is acted upon; a 360-degree feedback is used; developing subordinates is an accepted responsibility.

TABLE A-2 Resources and Capabilities Category (continued)

Characteristics	**Performance Level**	**Descriptions**
People Development	Stage 1	No training or development programs are available; there is little encouragement for employees to improve their skills.
	Stage 2	Training programs are left to the individual to pursue; training is secondary to service and is not fully budgeted.
	Stage 3	Career development programs are in place; training is available at all levels and is given priority; cross-functional development opportunities are encouraged.
	Stage 4	Interfunctional and international career opportunities are available; learning by teaching others is encouraged; training time is fully budgeted to avoid service conflicts; the faculty and students at internal training sessions are drawn from all levels of the organization; time off without pay is an option to get further training; off-site collaborations are used to expand knowledge.
Budget/ Funding	Stage 1	Budgets are last year's plus inflation, at best; budgets are severely constrained; mid-year cuts in budgets are made common.
	Stage 2	Major projects are constantly in jeopardy because of uncertainty in year-to-year funding; the number of new programs is limited; no new construction programs are funded.
	Stage 3	Budgets are linked to strategy; budget levels are determined by customers in negotiation with R&D personnel; one-year time horizons with some following year expectations are typical; resources are leveraged through creative approaches, such as collaborations with industry and academia; management is knowledgeable about funding sources.
	Stage 4	Budgets are strongly tied to the organization's strategy; budget levels are determined during strategy-setting exercises; time horizons are three years; adjustments are made at the end of each year; a backlog of high-quality unfunded projects is maintained to take advantage of any funding that becomes available.

TABLE A-2 Resources and Capabilities Category (continued)

Characteristics	Performance Level	Descriptions
RD&E Capabilities, Skills, Talents	Stage 1	Technical skills, capabilities, and talents are inadequate to support current and future customer requirements; few new techniques and skills are acquired via new hire, continuing education or retraining of personnel; personnel cannot fully operate or maintain available equipment; continuing education is not promoted, encouraged, or funded.
	Stage 2	Plans are developed and funding is provided for maintaining the present core capabilities; personnel are trained to operate and maintain equipment and use equipment as specified by the manufacturer; personnel skills are current and competent for their technical specialties.
	Stage 3	The organization possesses the skills and talents to fulfill customer requirements for the foreseeable future; new and innovative techniques, skills, and processes are incorporated into RD&E processes; newly acquired skills result in improved product engineering, manufacturing, or performance; new personnel are recruited to bring state-of-the-art techniques into the organization; personnel are encouraged to participate in formal continuing education programs; members of the research staff are encouraged to participate in professional societies, serve on external committees, etc.; program managers recognize new skills that will benefit their programs and plan for the acquisition of these skills and talents.
	Stage 4	The research and support staffs are recognized as possessing superb technical and administrative skills and talents; many members of the support staff are recognized as artisans of their trade; research personnel incorporate state-of-the-art techniques into their work and develop pioneering methods of their own; a clearly articulated plan describes how needs and voids in core capabilities are identified and filled; new capabilities that must be developed are also addressed and acted upon; a growing inventory of skills is maintained.

TABLE A-2 Resources and Capabilities Category (continued)

Characteristics	Performance Level	Descriptions
Intellectual Property	Stage 1	Intellectual property is considered the responsibility of the legal department.
	Stage 2	Intellectual property is considered the responsibility of the technology people; modest recognition is given for patents regardless of value.
	Stage 3	Issues become a shared concern for the organization and technology unit; selective patenting is facilitated by patent liaisons or people who have a good understanding of selection criteria.
	Stage 4	Issues are addressed as part of the strategic planning process and are reviewed periodically; licensing is used to speed progress and learning.

TABLE A-2 Resources and Capabilities Category (continued)

Characteristics	Performance Level	Descriptions
Technology Sourcing	Stage 1	The organization relies on internally-developed technology; work is contracted out on an ad hoc basis with little or no planning; contract managers do not ensure that statements of work are fulfilled on time or on budget; no formalized processes are used to determine what work should be outsourced.
	Stage 2	Working relationships with universities and other groups have been established; outside participation in professional associations is encouraged; there is no external technology sourcing process but there is a fit with the organization's plans; products and services are obtained from external sources to fulfill the statement of work.
	Stage 3	Ongoing relationships with universities, other government labs, and private companies are viewed strategically; the organization is recognized as a "smart buyer" of services and work of other parties; clear make-vs.-buy decisions and criteria are established; outside work is managed in detail; the contribution of external work is clearly demonstrated and adds value and reduces cycle time to the organization.
	Stage 4	Partnerships and contracts with organizations that are recognized as the best in their field complement RD&E programs and result in leap-ahead (and occasional breakthrough) technological advances; the organization takes a leadership role in professional societies; outsourcing is considered strategically; establishing alliances and collaborations is considered to be a critical competence; buy-manage-do decisions are based on an established process with clearly identified criteria.

TABLE A-2 Resources and Capabilities Category (continued)

Characteristics	Performance Level	Descriptions
Information Technology	Stage 1	Computer hardware and software are not available at every work station; software and hardware are two generations or more out of date; modes of communication are determined locally; access to hardware is determined by rank; training in a computer skill is left to the employee; employees are not linked electronically.
	Stage 2	Information technology is used as a tool by research and support personnel, and it increases productivity and ultimately decreases the organization's overhead; acquisition of new hardware and software is adequately funded; training and technical support are available; employees are linked electronically internally and externally; universal systems are agreed upon; in-house training in computer skills is available.
	Stage 3	An information technology strategy guides program direction; systems are more standardized and are up-to-date; computers are widely used by management; routine activities, such as keeping time records and expense accounts, are dealt with on line; networking is encouraged; employees are expected to have good information technology skills; technical support is abundant; the staff is educated in the use and application of the technology.
	Stage 4	Information technology enables rethinking how RD&E is done; standard tools are used organization-wide; these tools are tailored to specific business applications; systems are used to share best practices, team charters, financial information, and project tracking.

TABLE A-2 Resources and Capabilities Category (continued)

Characteristics	Performance Level	Descriptions
Facilities and Infrastructure	Stage 1	Equipment and facilities are not well maintained and tend to be out-of-date; preventive maintenance is seldom performed; equipment is operated only in the daytime.
	Stage 2	Facilities and equipment are satisfactory to meet current needs; there is a program for the routine maintenance and upgrading of equipment; some consideration is given to safety; shifts are adjusted to extend the time equipment can be used.
	Stage 3	Safety is critically important in operating equipment, and the work environment is free of hazards; facilities are environmentally controlled year-round; equipment is modern and well maintained; budgets allow for preventive maintenance, upgrading, and replacement of equipment; the use of the equipment is extended by electronic monitoring.
	Stage 4	Facilities and equipment are state of the art; inspection and training opportunities are considered important; there is pride in the appearance and safety/regulatory records; safety/regulatory capability is recognized externally; equipment is in use most of the day, and much of it is operated around the clock by electronic monitors.

TABLE A-3 Strategic Vision Category

Characteristics	Performance Level	Descriptions
Mission and Vision	Stage 1	Mission and vision statements are not well articulated or linked; senior management has trouble communicating the mission and vision.
	Stage 2	There is a discontinuity between function in (the mission and vision are clear to some but not to others); the mission statement is a wish list but does not address how the technical expertise is to be acquired; an attempt is made to develop a technology mission and vision statement.
	Stage 3	The mission and vision are consistent, and the message is clear to most employees; there is a tendency to want to be all things to all people; the mission and vision provide a "guide to action" for technical programs.
	Stage 4	There is a shared understanding of the mission and vision throughout the organization; technology is understood to contribute to shaping long-term strategy; core technologies are characterized and are consistent with mission and vision; resources are aligned with the research strategy.

TABLE A-3 Strategic Vision Category (continued)

Characteristics	Performance Level	Descriptions
Strategic Plan	Stage 1	There is no plan, only a portfolio of projects.
	Stage 2	A strategic planning process identifying the organization's role within the Army's strategic plan and within the organization is in place; senior management enlists the support of research and support staff to draft and implement the strategic plan through the business and annual plans; information on long-term customer needs is inadequate; a technology plan has been added after the fact.
	Stage 3	The fit of projects with the Army and organization's strategic plans is clear and operational; guides are used for prioritizing project within the function; the strategic plan is driven by organization's strategy; the plan details how the organization will achieve its objectives; technology management is invited to provide input to the strategic plan.
	Stage 4	The plans for all functions are fully integrated; plans include manpower, information technology, and budget and timing; plans specify the development path for product, process, and support technologies; the planning horizon for the strategic plan is sufficient to anticipate the major needs of the Army and joint services; technology management is an integral aspect of the business strategy.

TABLE A-3 Strategic Vision Category (continued)

Characteristics	Performance Level	Descriptions
Stakeholder Buy-In	Stage 1	The strategic vision and research plan either have not been communicated to the RD&E stakeholders or have not been articulated well and are misunderstood; stakeholder response to the vision and research plan is either negative or indifferent.
	Stage 2	A strategic vision is spelled out and understood by most stakeholders; the vision makes all major initiatives readily understandable.
	Stage 3	The strategic vision "speaks" to all stakeholders, even if they have not been involved in creating it; customers and disinterested parties understand the research plan and advocate providing adequate resources to implement the plan.
	Stage 4	The strategic vision is so clearly articulated that stakeholders lobby Army and DoD planners to implement the research plan fully; stakeholder support for the organization's vision and the research plan is so strong that resources are reprogrammed from other accounts to implement the vision.

TABLE A-3 Strategic Vision Category (continued)

Characteristics	Performance Level	Descriptions
Leadership	Stage 1	The commitment of the senior leadership to the strategic vision or research plan is poorly communicated to the staff; administrative and product development managers are not involved in planning the direction of future research or developing the business plan; personnel are suspicious or do not trust the organization's leadership; stakeholders view the senior leadership as ineffectual and reactive.
	Stage 2	The strategic vision and research plan are understood by the staff; resources (i.e., time, personnel, and dollars) are aligned to meet these plans; the staff trusts senior leadership and is receptive to new ideas and re-engineering opportunities.
	Stage 3	Management and staff co-develop plans that are understood and embraced by staff and stakeholders alike; ideas flow freely and in both directions between management and staff.
	Stage 4	The leadership has created an air of excitement and commitment throughout the entire organization; bold and creative ideas are encouraged and funded; RD&E successes are rapidly exploited, and ideas are rewarded; failure is considered an opportunity to learn.

TABLE A-4 Value Creation Category

Characteristics	Performance Level	Descriptions
Portfolio Selection	Stage 1	There is no project planning or monitoring and little interfunctional participation in project teams; products are developed that do not meet customer needs because of little customer input.
	Stage 2	An analytical process to examine the product portfolio is used to design and field products that have greater value and customer acceptance; a major focus is the expansion of successful business areas; the organization is risk averse so new research approaches are not encouraged and major changes are made to products after they have been introduced.
	Stage 3	Portfolio analyses of programs are an integral part of the strategic planning process; there is broad and active customer involvement in the portfolio analysis; risk analysis is incorporated at key phases; projects are schedule driven; criteria are in place for go/no go decisions; there are regular milestone reviews of projects; probability of success is built into the portfolio process, identifying clear values and trade-offs, as is a prioritization process.
	Stage 4	Project analysis involves framing the project, identifying alternatives, and making a commitment to action; decision and risk methodologies are used frequently; linkage between criteria and business strategy and line strategy is clear; portfolio analyses result in RD&E processes that yield products and services with excellent value, performance, and customer acceptance.

TABLE A-4 Value Creation Category (continued)

Characteristics	Performance Level	Descriptions
Cycle Time and Responsiveness	Stage 1	The cycle time for project completion is longer than anticipated, milestones are routinely missed, and program delays result in increased end-item cost; research programs do not anticipate customer needs; management and staff are not flexible to modifications of product requirements.
	Stage 2	The elapsed time from project initiation to project completion is measured and can be reliably forecasted; research programs are on time and on budget.
	Stage 3	RD&E programs are initiated and completed significantly faster than similar government or commercial programs; research staff is responsive to "quick fixes," and numerous examples of quick fixes to major products are readily available; senior management ensures that adequate resources are reprogrammed to fulfill requests for quick fixes.
	Stage 4	RD&E programs are initiated and completed quicker than similar government or commercial programs; innovative processes and technical solutions reduce typical quick-fix response times by nearly half; staff monitors foreign and domestic industrial and academic research for solutions to new and unanticipated technical problems; customers directly and indirectly express gratitude for responsive quick fixes.

TABLE A-4 Value Creation Category (continued)

Characteristics	Performance Level	Descriptions
Value of Work in Progress	Stage 1	No evaluations of historical RD&E programs are available for comparison to current programs; no methodology is in place to assess current RD&E programs; customer perception of prior RD&E programs is predominantly critical and negative; little or no value is placed upon the current programs by the customers.
	Stage 2	A database on select historical RD&E programs and all current programs is available; current RD&E programs are vividly described, and these descriptions are used during peer-review discussions to justify programs and prioritize personnel and budget requests; customer perception of prior and current RD&E programs is generally positive (i.e., the products and services generally meet user requirements and are delivered on time and on budget).
	Stage 3	A database is maintained on all past major projects (e.g., for the last decade) and their primary and secondary impacts; the database is used for comparison with current RD&E programs; leadership creates a scale to compare the potential value of current programs to previous programs and show improvements; customers rate RD&E programs as very good (i.e., products are expected to fully meet or exceed customer requirements; products are perceived as likely to be better than the ones they replace).
	Stage 4	A complete historical database and evaluation methodology are used to demonstrate the value of the organization's products and services; data are used to justify and defend program expenditures; customers rate products and services as excellent (e.g., product performance exceeds customer expectations); product performance exceeds anything projected to be available from domestic and foreign sources for at least several years.

TABLE A-5 Quality Focus Category

Characteristics	Performance Level	Descriptions
Capacity for Breakthroughs	Stage 1	RD&E programs are routine and unimaginative; there is no evidence of imaginative or innovative solutions being applied to RD&E tasks; resources are directed to meeting specific customer requirements only.
	Stage 2	RD&E programs are characterized by steady but incremental improvement; several innovative solutions can be pointed out; minimal funding is available for programs that anticipate future military requirements.
	Stage 3	Although most programs are characterized by incremental improvements in technology, the organization has demonstrated several leap-ahead improvements; the organization encourages and funds opportunities to seek truly innovative, moderate-risk solutions.
	Stage 4	Unexpected innovations based on breakthroughs in technology occur fairly regularly among internal and external (cooperative) RD&E programs; moderate- and high-risk research that offers high return receives stable funding; numerous examples of breakthrough research are cited from the previous five to ten years.

TABLE A-5 Quality Focus Category (continued)

Characteristics	Performance Level	Descriptions
Continuous Improvement	Stage 1	No apparent effort is made by management to improve processes; solutions from industry and academia are discounted as "not invented here."
	Stage 2	A quality model has been adopted but is not universal; innovative solutions are encouraged, and staff members frequently make suggestions for improvement; some training is offered; ideas for improvement are solicited and acted upon.
	Stage 3	Learning from others is encouraged; quality audits are performed periodically by internal and external review groups; report cards are issued annually by senior leadership; external surveys are conducted; ISO 9000 certification is widely sought; internal quality assessments are used.
	Stage 4	Greater productivity, enhanced research and product quality, improved customer involvement and satisfaction, and continuing education of the workforce are areas of primary interest to senior management; there is a systematic analysis of research and support processes to eliminate non-value-added activities; benchmarking is used proactively; best practices are shared; focus is on the external customer; the Baldrige National Quality Award criteria are used to drive improvements in performance.
Teams	Stage 1	There is frequent turnover of team staffing; project leaders are not trained and their roles are not defined; charters for teams are not clear.
	Stage 2	There is some interfunctional participation; teams are mostly stable but run into conflicts with functional priorities; project leaders are given some guidance; teams have formal charters.
	Stage 3	Interfunctional teams are used when needed; responsibility are delegated to teams; training for project leaders is provided; charters are published widely; a process is in place to facilitate interteam communications.
	Stage 4	Teams are critical to success; there are rewards for team performance; teams are often self-managed.

TABLE A-5 Quality Focus Category (continued)

Characteristics	Performance Level	Descriptions
Evaluation and Rewards	Stage 1	The process is a mystery.
	Stage 2	There are no meaningful rewards except for salary increases; there is no correlation between rewards and performance level.
	Stage 3	Written evaluations and periodic reviews are utilized; focus is on improvements in performance; rewards and recognition relate to performance; recognition is given for suggestions and ideas.
	Stage 4	Multilevel feedback is used to focus on improvement; team and individual awards are given; a single committee makes decisions on salaries, rewards, and promotions for all business functions.
Project Management	Stage 1	Each project is treated as a new experience; the management process is ad hoc.
	Stage 2	Several stage-gate models[1] are used on most projects; the process itself is not reviewed.
	Stage 3	A uniform approach to project management is used; a strong focus is on up-front planning; reducing cycle time is an important factor; some projects are reviewed, but there is no ongoing use of reviews to improve the process.
	Stage 4	A standard methodology is used for all projects and is widely accepted; the methodology is applied to widely different projects; the inclusion of new technology is encouraged; each project is considered to be a learning opportunity, and there are formal ways to modify the process.

[1] A stage-gate model divides a process (like a product development model) into several subprocesses. At the end of each subprocess is a “gate.” Before passing through the gate, certain requirements must be met. Once those have been met, the organization can move to the next subprocess, which has its own gate. An efficient organization has a single stage-gate model, the benefit of which is that each team can learn from the prior team’s experience.

TABLE A-5 Quality Focus Category (continued)

Characteristics	Performance Level	Descriptions
Regulatory Compliance	Stage 1	Management shows no interest in complying with regulations; the prevailing attitude is "do what you can get away with."
	Stage 2	Formal policies are in place; internal audits are used to enforce compliance.
	Stage 3	A strong effort is made to comply; an organizational policy is in place that is supported by management's actions.
	Stage 4	Well publicized organizational ethics provide overall guidance; proactive efforts are made to protect the environment; management takes the lead in regulatory compliance.
Commitment to Quality	Stage 1	Management espouses a commitment to quality, but no formal process to review and evaluate quality is in place; some quality-related results are managed by exception; the quality of products and services varies between RD&E units in the organization.
	Stage 2	Management invests resources for total quality training and implementation; the variability of products and services is measured and tracked; personnel are aware of the importance of quality.
	Stage 3	Total quality implementation is a major goal in the organization's strategic plan; a framework and methodology for measuring and assessing quality is in place; measurable objectives for work-process improvement are established; there are methods (e.g., statistical process controls) to improve effectiveness and product quality with existing resources.
	Stage 4	The commitment to total quality is inherent and pervasive throughout the organization; the focus of all measurements is on optimizing the RD&E processes to deliver value; frameworks, such as ISO 9000/2 (international quality standards), the Baldrige National Quality Award criteria, or locally developed systems, are used for assessment; recommendations to improve quality are immediately funded and implemented.

TABLE A-5 Quality Focus Category (continued)

Characteristics	Performance Level	Descriptions
Process Management	Stage 1	The focus is not on core processes; activities are thought to be unrelated processes with no clear priorities.
	Stage 2	Some important processes emerge from the profusion of activities; some processes are managed systematically; processes are monitored against budgets and milestones.
	Stage 3	There is a high-level overview of the key processes; processes are prioritized; process performance is judged against external standards and internal milestones; senior leadership and staff are receptive to innovative ideas for improving work processes and procedures.
	Stage 4	Process management is well established and accepted; processes are recognized at the organizational level, the process level, and the job level; links between levels unify the strategy throughout the organization; the senior leadership strives to identify and incorporate best business practices into the organization.
Metrics	Stage 1	Focus is on the short term.
	Stage 2	Measures include customer satisfaction; the goal is to ensure that customer requirements are met; the search is for "the few key measures" of progress toward that goal.
	Stage 3	A variety of measures linked to the corporate goals are used; the organization recognizes that different measures are needed for different purposes; measures related to cost, time, and quality are used.
	Stage 4	A balanced list of measures is used to ensure that all key aspects of the organization are considered including financial, external and internal customers, innovation and learning and societal perspectives; the emphasis is on measuring customer value.

TABLE A-5 Quality Focus Category (continued)

Characteristics	Performance Level	Descriptions
Safety	Stage 1	Safety is not fully addressed; employees are chastised for accidents.
	Stage 2	Safety is said to be important, but management does not "walk the talk," and little thought is given to safety training.
	Stage 3	Managers "walk the talk"; safety awards are given for group successes; organizational standards are posted and compared to industry standards.
	Stage 4	Safety issues are addressed as part of strategic planning; employees receive behavioral modification training; safety is addressed at every management meeting; employees take pride in their safety records.

TABLE A-5 Quality Focus Category (continued)

Characteristics	Performance Level	Descriptions
Knowledge and Learning	Stage 1	Senior leadership is characterized as reactive; knowledge as an asset is not recognized; knowledge tends to be associated with degree level.
	Stage 2	Senior leadership recognizes and communicates the importance of organizational learning; personnel are well networked both inside and outside the organization; best practices are shared within functions but not beyond; knowledge tends to be associated with level in the company; new skills and techniques are acquired through new hires and continuing professional education.
	Stage 3	Organizational learning is characterized as adaptive; the need for sharing best practices is recognized; personnel are rewarded and encouraged for taking risks and entrepreneurial initiatives despite occasional mistakes; systems are in place to promote information-sharing; there are rewards for proactive information-sharing; employees are encouraged to take risks and are not chastised for failures.
	Stage 4	The concept of a "Learning Organization" is understood and valued by management; organizational learning is adaptive and anticipatory; the organization works to differentiate itself on the basis of the tacit and specific knowledge of its people; attempts are made to quantify the value of intangible assets.

Appendix B

Biographical Sketches of Committee Members

Francis G. Dwyer, NAE, *chair*, earned his B.S. in chemical engineering from Villanova University and his M.S. and Ph.D. degrees in chemical engineering from the University of Pennsylvania. He retired in 1993 from Mobil Research and Development Corporation as a senior scientist and the manager of the Catalyst Research and Development Section. His wide range of experience with a variety of petroleum and petrochemical research, development, and manufacturing issues includes the development of the first zeolite containing cracking catalysts; a family of catalysts for a wide spectrum of applications; the Mobil/Badger Ethylbenzene Process (a heterogeneous nonpolluting process used in the manufacture of styrene worldwide); and pollution abatement catalysts.

Jerome S. Schultz, NAE, *vice chair*, earned his B.S. and M.S. degrees in chemical engineering from Columbia University and a Ph.D. in biochemistry from the University of Wisconsin. He is the director of the Center for Biotechnology and Bioengineering at the University of Pittsburgh. Dr. Schultz is a renowned expert in the field of biosensors, including biorecognition functions, bioreceptors, and synthetic membranes.

Klaus Biemann, NAS, earned a Ph.D. in organic chemistry from the University of Innsbruck. He recently retired as a professor of chemistry at the Massachusetts Institute of Technology where he taught since 1957. His research interests have included the structure and synthesis of natural products and the development of mass spectrometric techniques, especially in combination with gas chromatography, also the identification of combustion products of fossil fuels, the correlation of DNA sequence and protein structure, and protein sequencing by high-performance, tandem mass spectrometry.

Harold S. Blackman earned his B.A.E. in secondary education, with a major in biological science and his M.S. and Ph.D. in educational psychology from Arizona State University. Dr. Blackman is currently manager of the Engineering Analysis Department at the Idaho National Engineering Laboratory. He has specialized in quantitative methods and research methodology, as applied in psychology, engineering, and education. Most recently his research has been in the assessment of human error and cognition as it relates to complex human performance.

Barbara G. Callahan earned her A.B. in biology/chemistry from Emmanuel College, her M.S. in biology from Rivier College, and her Ph.D. in toxicology from Northeastern University. She is currently director of Fluor Daniel GTI Risk Assessment Services. Dr. Callahan has performed evaluations of sites contaminated with pesticides, PCBs, heavy metals, and PAHS. She is also a member of several national committees that study the effects of acute exposure to toxicants on human health after accidental release under emergency conditions. She has been awarded the U.S. Army Environmental Hygiene Agency Commander's Medallion.

Sanford S. Leffingwell earned his A.B. from Harvard University, his M.P.H. from The Johns Hopkins School of Hygiene and Public Health, and his M.D. from the University of Colorado School of Medicine. Following a career with the U.S. Public Health Service, he became a consultant and instructor for HLM Consultants, where he works on occupational and environmental clinical, health, and safety issues.

Derek L. Ransley is currently president of Ransley & Associates in Lafayette, California. From 1962 to 1996, he worked at the Chevron research and development organization. He received his B.Sc. in chemistry from the University of Wales and his M.S. and Ph.D. degrees in organic chemistry from Yale University. He is currently a consultant on benchmarking and best practices related to technology and technology management.

Ludwig Rebenfeld earned his B.S. in chemistry from the University of Lowell and his Ph.D. in chemistry from Princeton University. He is currently president emeritus and research associate of the Textile Research Institute. He has been a lecturer with the rank of professor at Princeton University since 1971 and is currently the editor of Textile Research Journal. He previously served as chairman of the Advisory Board on Military Personnel Supplies and is a past member of the National Research Council Board on Army Science and Technology.

William G. Reifenrath received his B.S. degree in chemistry from the University of Nebraska and continued at the College of Pharmacy to earn a Ph.D. in medicinal chemistry. He is presently a research chemist at the University of California at Berkeley and also directs Reifenrath Consulting and Research, a contract research company specializing in skin toxicology and pharmacology.

Jack Throck Watson earned his B.S. in chemistry from Iowa State University and his Ph.D. in analytical chemistry from the Massachusetts Institute of Technology. He is a professor of biochemistry at Michigan State University and a principal investigator at the Michigan State University Mass Spectrometry Facility. His research interests include the study of a wide variety of proteins by mass spectrometry, as well as application of state-of-the-art methodologies and advancements in the field of mass spectrometry.