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EMERGING TECHNOLOGIES PROGRAM

INTEGRATION REPORT
VOLUME I

NARRATIVE, ANALYSES AND ASSESSMENTS

PREPARED FOR
THE OFFICE OF THE DEPUTY UNDER SECRETARY OF DEFENSE,
RESEARCH AND ADVANCED TECHNOLOGY

PREPARED BY
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The opinions expressed in this report reflect the views of SAIC, the panel chairmen and the individual panelists who contributed to this report. They do not necessarily represent the positions of the panelists' organizations or of the US Government.

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The objective of the Emerging Technologies Program is to identify key technology areas of high interest to the DoD, for investment purposes. The two volumes of this integration report assess and synthesize information gathered through a Delphi survey, defense needs prioritization workshops, and assessments of high priority areas. Volume I of the report contains the actual narrative, analysis, and assessments that have been developed; in Volume II are the background, Delphi and workshop data from which the analysis and assessments were drawn. The specific technologies considered are: command, control, and communications; directed energy; manufacturing; biotechnology; human factors; mobility, search and surveillance; and electronic warfare.

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BLOCK 18. ELECTRONIC WARFARE, SURVEILLANCE

OVERVIEW OF THE EMERGING TECHNOLOGIES PROGRAM

PURPOSE: The Emerging Technologies Program is tasked to assist the DoD to identify and assess promising new technologies, in order to shorten the time between research "ideas" and defense system applications and to avoid technological surprises.

This report is one of a series under the Emerging Technologies (ET) Program. Each ET panel is tasked with identifying and assessing evolutionary changes. It is not the purpose of the ET Program to attempt to predict "revolutionary" changes in technology, which by their nature cannot be predicted. This practical constraint, inherent in technology forecasting, highlights the importance of sustaining a strong technology base program to avail of future technological changes in whatever form they appear.

BACKGROUND: Technology forecasting is not a perfect science, nor will it become such in the near future. However, by diligent, thorough and continuous monitoring of the progress of specific areas of basic and applied research and carefully nurturing their development, one can predict fairly accurately their applicability and time frame of development. Lasers, for example, from the time of their discovery, clearly had a military potential- although it was not clear in the beginning how they would be used, within a decade they were utilized in operational weapon systems. Today, other areas have less clear military potential but, once identified, they also must be followed due to their uncertain but potentially revolutionary impact on current or future weapon systems.

APPROACH:

- Survey a broad coverage of areas of potential interest to the military and to commercial markets.
- Canvass the DoD user community for current and future technological needs.
- Analyze the results of the two processes above, to form a select list of technologies judged to be potentially of high priority. This list is then assessed in considerable depth by panels composed of US experts.
- Integrate the in-depth assessment reports with other studies performed by SAIC in assessing the state of technological progress in other countries, including the Soviet Union and Japan.

The SAIC Emerging Technologies Program is therefore conducted in four repeatable phases: Phase I--A broad coverage study utilizing the Delphi process; Phase II--A DoD application community Prioritization Workshop to identify Defense needs; Phase III--In-depth assessments of high priority areas; and Phase IV--Annual update and Integration Report.

Accordingly, this in-depth Integration Report assesses and synthesizes information developed by the ET Program with data from several other Government-sponsored projects which address the state of world-wide technology. This Integration Report details the US position and identifies specific technologies in which research appears appropriate, to ensure that the US leadership position will be maintained.

SUMMARY: The objective of the Emerging Technologies Program is to generate a new *methodology for identifying key technology* areas of high interest to the DoD, and to apply this methodology to assist investment decisions affecting the Science and Technology/Technology Base program (6.1, 6.2, and 6.3A). This effort is particularly timely because, with shrinking Federal budgets and major technological challenges from abroad, the DoD requires a uniform process that allows continuing technology assessments, cutting across a wide spectrum of emerging technologies.

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EMERGING TECHNOLOGIES PROGRAM

INTEGRATION REPORT

VOLUME I—NARRATIVE, ANALYSES AND ASSESSMENTS

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PREFACE

This report is one of a series under the Emerging Technologies (ET) Program. Each ET panel is tasked with identifying and assessing evolutionary changes. It is not the purpose of the ET Program to attempt to predict "revolutionary" changes in technology, which by their nature cannot be predicted. This practical constraint, inherent in technology forecasting, highlights the importance of sustaining a strong technology base program to avail of future technological changes in whatever form they appear.

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CHAPTER I
EXECUTIVE SUMMARY

A. OVERVIEW OF THE EMERGING TECHNOLOGIES PROGRAM

The US government and industry have made very large investments in scientific and engineering research since World War II. The sponsors of this research have assumed that return on their investment would come from the head start they would have in applying the knowledge gained. Technological leadership, in both the civil and the defense sectors, would follow naturally from our continuing leadership in research.

Recent trends have brought into question several elements of this line of reasoning. While the United States continues to spend more on research and development than any other nation, large investments by other nations in education, training, research and development have begun to reduce or reverse US dominance of high technology industries. This narrowing of the technological gap between the United States and the rest of the world is likely to continue.

To stay ahead, the United States must take measures to ensure that new technologies, most often still developed first here in the United States as a result of our large investment in basic research, are also **applied** first in the United States. This matter of being first in applying research is complicated by the fact that, in many important areas of technology, there has been a shrinkage of time between basic research and application. In some areas, the traditional time span of 10, 20 or even 30 years has shrunk to three to five years, requiring much quicker technology transition decisions. In other areas, like computer software, biotechnology, artificial intelligence, and materials processing, the gap between research and application may be even shorter.

Many of the high-technology industries now subject to world competition have dual applications, to production for defense as well as for civil systems. In these areas, and in areas where the application of new technology to defense systems is more direct and automatic, the Department of Defense (DoD) has special responsibility. The offices charged with maintaining the qualitative edge that our military systems now provide need to establish and sustain acute awareness of newly available and prospective technological opportunities.

The Office of the Deputy Under Secretary of Defense, Research and Advanced Technology (ODUSD/R&AT), sponsors the Emerging Technologies Program to help the office identify and assess progress in those rapidly advancing and emerging technologies that have the most potential to improve future national defense capabilities. This program helps the office assure that opportunities are not missed for timely, high-leverage investments by DoD at the early stages of the research and development cycle, when such investments can shorten the lag between proof of principle and application. The program also provides information that may assist the office in choosing among competing demands for such investments, and in defending these investments in internal competition with other, nearer-term DoD development efforts. Finally, the ET Program can also help DoD to avoid technological surprises by adversaries.

Science Applications International Corporation (SAIC) developed a program which responds to these defense needs. Four phases of activities were designed to meet the goals of the Emerging Technologies Program.

First, SAIC organized a Delphi Survey* to identify and characterize a wide variety of emerging technologies that might be available for application in systems within the next 20 years. Three rounds of Delphi questionnaires and responses identified potentially important technologies that were past proof of principle, and deserving of research investment. The nationally recognized technology experts that participated in this phase of the program were chosen to cover a wide range of disciplines and to come from a wide range of professional settings in the civilian and defense technology communities.

Second, we brought the Delphi respondents' brief descriptions and discussions of significance to a set of workshop session meetings with DoD system developers. The DoD workshop participants had an opportunity to "shop" the list (adding some new emerging technologies that they thought should be considered), and identified potential applications of the emerging technologies in their development areas. Then the workshop participants identified those technologies with the most potential for their future applications, with emphasis on opportunities for very great impact on our defense capabilities.

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* The Delphi technique taps the knowledge and intuition of a group of experts by having them answer several rounds of questions. The exercise is highly structured, to allow the experts to consider their colleagues' ideas in refining their own thinking, while avoiding constraints and pressure that often arise in face-to-face meetings.

Third, following the workshop, SAIC prepared (in this report) a synthesis of the Delphi-identified technology forecasts and the workshop session results, assessing the possible significance of these emerging technologies for future defense systems. One product of this synthesis is a consensus list of 14 high priority areas in which emerging technologies have potential for especially large (or very wide) impact on future defense capabilities.

Finally, the 14 high priority areas are now the focus of the fourth phase of the Emerging Technologies Program. In this phase, a panel of experts in each of the areas selected conducts a worldwide assessment of the current, and likely future, state of the art. Because these panels are far more focused than the broad Delphi effort, we expect these assessments and predictions to be far more comprehensive (within each area), more authoritative, more specific, and (therefore) more useful in program planning and assessment. In this phase, we expect the panels to be helped significantly by the availability of previous assessments of foreign applied science and technology prepared by SAIC under the sponsorship of other government agencies--reports of the Foreign Applied Sciences Assessment Center (FASAC), the Japanese Technology Evaluation Program (JTECH), and the Global Technology Evaluation Center (GTEC). The first such ET in-depth assessment panel, "III-V Microelectronics," has completed its report. The second ET panel is assessing "Machine-Intelligence/Machine Vision." Subsequent panel topics are to be selected by the Sponsor.

B. 1985 DELPHI SURVEY

Because the DoD is a minority investor in exploratory research, it is difficult for DoD research managers to develop a comprehensive understanding of the technologies viewed as most promising by the private sector. To provide something approaching as nearly as possible a comprehensive menu of key emerging technologies, SAIC used a Delphi Survey of a group of 91 experts, selected from universities, industry and government laboratories.

The Delphi technique[1] was originated by Olaf Helmer and Norman Dalkey at the Rand Corporation in 1953. It is intended to make the best use of a group of experts to obtain answers to questions involving their informed intuitive opinions. The method

1. Olaf Helmer, Looking Forward--A Guide to Future Research, Sage Publications, 1983.

obtain answers to questions involving their informed intuitive opinions. The method involves a series of questionnaires, with controlled feedback of the results of previous questionnaires at each stage in the series. In this feedback, there is no direct confrontation of one expert by another. An attempt is made not to associate opinions with specific individuals. These steps are taken to avoid the extraneous psychological factors that arise in decisions made by committees at meetings. The Delphi technique has been used in the past for a wide variety of technological forecasts.

Table I.1 lists the respondents who participated in one or more rounds of the Delphi Survey. The 24 participants designated with a "T" participated in the initial trial round.

The first round was designed to produce an initial list of technologies, to serve as candidates for consideration by the larger group. Their responses also served as exemplars of the responses desired in the second and following rounds.

In defining what level of aggregation comprises "a technology" we have tried to conform to the terminology used by the Office of the Secretary of Defense (OSD) (e.g., in the USDRE posture statement) to define a "technology area." We then solicited, in the Delphi Survey, identification of "technologies" of a more specific nature that could be grouped within technology areas. The first questionnaire asked for descriptions of technologies that "could be made to emerge from the concept stage" within the next 15 years, plus potential applications, plus "Why do you think it is possible?".

After some screening by SAIC for consistency with the Survey's definition of a technology, the respondents' descriptions were used essentially verbatim as inputs to the second Delphi round. There were 65 "candidate technologies." The respondents were asked to estimate the date of availability of the technology (in five-year increments) and its value (on a five-point scale). Table I.2 illustrates the general nature of the responses. The respondents valued most of the candidate technologies selected in the first round as above average. There was a wide spread in the estimated dates of availability, possibly due to individual differences in interpretation of the meaning of "availability" or of the definition of the technology.

We asked the second round participants to suggest additional candidate emerging technologies, comparable to those provided in response to the first round questionnaire. The SAIC staff chose 172 additional candidate emerging technologies to be added to the 65 candidates suggested in round one, for a total of 237 candidates to be considered in the next round.

Table I.1
DELPHI SURVEY RESPONDENTS

1. ALBUS, Dr. James S. (T)
2. ATLAS, Dr. David (T)
3. BALDESCHWIELER, Dr. John (T)
4. BANKS, Dr. H. Thomas
5. BARSCHALL, Dr. H. H.
6. BATES, Dr. John B.
7. BAUGHMAN, Dr. Raymond
8. BEDARD, Dr. Fernand
9. BEMENT, Jr., Dr. Arden L. (T)
10. BENNETT, M.D., Dr. Ivan (T)
11. BRINKMAN, Dr. William F.
12. BRODSKY, Dr. Marc H.
13. BROWN, Dr. William M. (T)
14. BYER, Dr. Robert L. (T)
15. CARLSON, Jr., Dr. Herbert C.
16. CAULFIELD, Dr. John H.
17. CHURCHILL, Dr. Stuart W.
18. CLIFFORD, Dr. Steven F.
19. COFFEY, Dr. Timothy (T)
20. COOPER, Dr. Leon N
21. CURRAN, Dr. Edward T.
22. DAVIS, Dr. Steven J.
23. DEAN, Dr. Anthony M.
24. FAETH, Dr. Gerald
25. FETTERMAN, Dr. Harold
26. FRANKEN, Dr. Peter A. (T)
27. GEBALLE, Dr. Theodore H.
28. GEBHARDT, Dr. Joseph J.
29. GLASSMAN, Dr. Irvin (T)
30. GLIMM, Dr. James
31. GREGG, Dr. Michael C. (T)
32. HADDAD, Dr. Genevieve M.
33. HAMMOND, Dr. George S.
34. HAPPER, Jr., Prof. William
35. HEICHE, Dr. Gerhard F. A.
36. HOSLER, Dr. Charles L.
37. INFANTE, Dr. Ettore F.
38. KAHAN, Dr. William M.
39. KAILATH, Dr. Thomas (T)
40. KAPLAN, Dr. Richard E.
41. KATZ, Dr. Robert N.
42. KNAPP, Dr. Edward A. (T)
43. KRISTIANSEN, Dr. Magne
44. KROGER, Dr. Harry
45. KRUGER, Dr. Jerome E.
46. KUO, Dr. Kenneth K.
47. LANZEROTTI, Dr. Louis J.
48. LAUER, Dr. James L.
49. LEWIS, Dr. Clark H. (T)
50. LILLY, Dr. Douglas K.
51. LUDEMA, Dr. Kenneth C.
52. MILLER, Dr. G. L.
53. MOORE-EDE, Dr. Martin C.
54. MUNSON, Mr. John
55. NARATH, Dr. Al
56. NASTROM, Dr. Gregory D. (T)
57. NOWLIN, Jr., Dr. Worth D.
58. PATEL, Dr. Chandra Kumar
59. PENZIAS, Dr. Arno A. (T)
60. PEW, Dr. Richard W.
61. REDDY, Dr. Raj (T)
62. REDIKER, Dr. Robert H.
63. RHEINBOLDT, Dr. Werner C.
64. RICE, Dr. John R.
65. ROBERTS, Dr. Fred S.
66. SCARF, Dr. Frederick L.
67. SCHAFER, Dr. Ronald W.
68. SCHAPERY, Dr. Richard A.
69. SCHMITT, Dr. Roman A.
70. SCHOLTZ, Dr. Robert A.
71. SCULLY, Dr. Marlan O.
72. SEERY, Dr. Daniel J.
73. SENIOR, Dr. Thomas B. A. (T)
74. SMITH, Dr. James A.
75. SPICER, Dr. William E. (T)
76. SPINDEL, Dr. Robert C.
77. STEINBERG, Dr. M. A.
78. TOWNES, Prof. Charles
79. TRICOLES, Dr. Gus P.
80. TSUI, Dr. Dan
81. ULMER, Dr. Kevin M. (T)
82. WALKER, Dr. Raymond F. (T)
83. WEEKS, Dr. Wilford
84. WEINTRAUB, Dr. Daniel J. (T)
85. WINGARD, Jr., Dr. Lemuel
86. WOODALL, Dr. Jerry M.
87. YARIV, Dr. Amnon
88. ZIMET, Dr. Eli

89-91. "Anonymous Respondents"

Key: (T) = participant in first, trial Delphi round

Table I.2 SAMPLE SECOND ROUND DELPHI POLL RESULTS

OPTICS AND LASERS

	VALUE					AVAILABILITY							
	0	1	2	3	4	1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-never	Prefer not to answer	no dates
1. Ultra low-loss fiber optics	1	2	8	22	22	6	32	8	6	1	1	20	1
2. Sub-wavelength optical imaging by gradient techniques	1	2	8	9	4	1	11	8	3	1		51	
3. Optical fiber sensors for measurement of physical parameters	1	2	16	33	8	11	32	7	5	2		15	3
4. Optical fiber sensors for measurement of chemical properties	1	5	21	19	7	4	26	11	4	1	1	22	6
5. Real-time holographic interferometry through fiber optics	1	4	14	14	6	2	13	12	7		3	36	2
6. Coherent gamma-ray sources (e.g., X-ray lasers)		5	8	16	18	1	12	7	15	6	3	28	3
7. Steerable laser diode arrays at powers of approximately 1 kw/cm^2		1	3	22	11		12	6	12	6		38	1
8. Rare-gas halide excimer lasers with high efficiency and high energy output		2	7	23	6	1	16	10	7	4		37	
9. Nd: YAG lasers with average 1 kw, for manufacturing		2	23	14	3	1	24	9	5	2		33	1
10. Co_2 lasers for manufacturing with power 10 kw		2	22	14	6	6	25	7	3	1		31	2

Because the number of candidate technologies in the third round questionnaire was so large, we divided the technologies into 12 categories, each intended to be homogeneous and a likely "area of expertise." There were about 20 items in each category, as shown in Table I.3. The respondents picked the three or four categories in which they felt most expert and answered only in those. They were asked for availability dates; specific milestones/research developments required to realize the technology (as justification of their estimate of availability dates); judgments of the value of each technology; and specific applications (as justification of their estimate of "value"). Sixty-five participants responded in this round. On the average, each respondent answered in three technology categories. The number of self-declared experts varied among categories, from a low of 10 for biotechnology and life sciences to a high of 24 for computers. Since respondents did not always address every technology within a category, the number of responses was very small for some technologies.

We assembled responses from the first three Delphi rounds to produce a composite worksheet for each technology, as exemplified in Figure I-1. The two figures at the top of these worksheets summarize the responses to questions concerning date of availability (left side) and value (right side). Solid lines correspond to Round Two, and dashed lines (with scales in parentheses) to Round Three. The remainder of the page lists the "needed developments" and potential "applications" as listed by respondents in Round Three.

C. 1985 EMERGING TECHNOLOGIES (ET) WORKSHOP

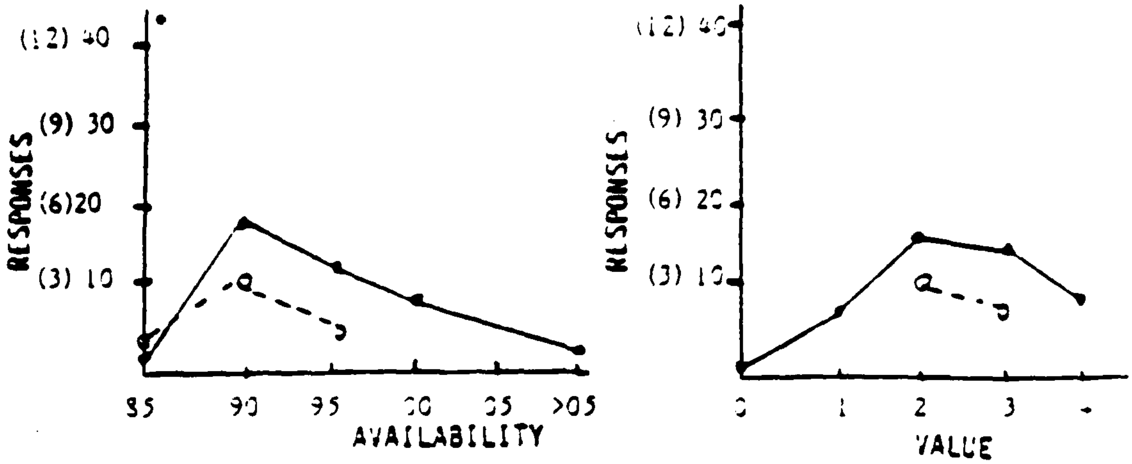
ET Workshops provide a forum wherein the DoD technologists (system developers) can identify current and future "needs" and select technologies (from the Delphi list) which seem most likely to satisfy these "needs." SAIC conducted the first of several planned Workshops at the US Naval Academy in Annapolis, MD on 17-19 June 1985. The meeting was unclassified. Participants included 128 DoD technical experts, mostly from Service laboratories, and selected invitees from other Government organizations such as NASA, DoE, OSTP, NSF and the Intelligence Community.

In preparing for this initial Workshop, SAIC first categorized DoD application areas into broad groups of applications. Some of these groups resembled mission areas, others were items of equipment, still others were information needs. There is no "best" set of categories, but for the purpose of organizing this Workshop we chose the 13 application or requirement areas listed on page I-10.

Table I.3
THIRD ROUND DELPHI TECHNOLOGIES

	TECHNOLOGY CATEGORY	NUMBER OF TECHNOLOGIES
A.	BIOTECHNOLOGY, MEDICINE AND LIFE SCIENCES	23
B.	CHEMISTRY AND CATALYSIS	12
C.	COMBUSTION, PROPULSION AND ENERGY	19
D.	COMMUNICATIONS, RADAR AND SIGNAL PROCESSING	20
E.	COMPUTERS	18
F.	DIRECTED ENERGY RELATED TECHNOLOGY	20
G.	ELECTRONIC MATERIALS AND DEVICES	25
H.	FLUID DYNAMICS	15
I.	MACROSCOPIC MATERIALS	25
J.	OPTICS AND LASERS	13
K.	REMOTE SENSING, OCEANOGRAPHY AND METEOROLOGY	25
L.	ROBOTICS, AUTOMATION AND MACHINE INTELLIGENCE	22

REAL-TIME HOLOGRAPHIC INTERFEROMETRY THROUGH FIBER OPTICS



NEEDED DEVELOPMENTS:

- Solution to the basic problem of image transmission in fibers.
- Coherent single mode fibers and fiber arrays.
- Fiber optic dividers, modulators.
- System development, especially sensor for long wavelengths and conversion of data to visible images.
- Innovative data processing that is rapid enough for "real-time" work.
- Demonstration in real working environments.

APPLICATIONS:

- Real time imaging with wavelengths long compared to visible light wavelengths.
- Vibration analysis of complicated structures; convenience of transport.
- Limited "internal" testing of apparatus.
- Robotics vision; quality control.
- Real time operational holography for diagnostics, without present size, handling and packaging constraints.
- Optional testing.

Figure I-1

Illustrative Composite Responses from
Delphi Rounds 2 and 3 for One Technology

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* The solid line refers to Round 2 and the "10's" scale; the dashed line refers to the Round 3 and the "3's" scale (in parentheses).

- Command, Control and Communications
  - electronics
  - computers, hardware & software including AI
  - man/machine interface
- Strategic Defense Initiative
- Search and Surveillance
  - target acquisition
  - CM & CCM
- Mobility (Vehicles)
  - air/land/sea
  - avionics & fire control
  - man/machine interface
- Propulsion and Power
  - airbreathing
  - rocket
  - stored energy
- Materials
  - electronic
  - non-metallic structural
  - metallic structural
  - protective
  - biotechnology
- Electronic Warfare
  - ASW
  - radar
  - microwave
- Manufacturing
  - robotics
  - machine vision
  - integrated cells (factory of the future)
- Weapons (non-nuclear)
  - missiles
  - explosives
  - flames
  - CW
  - mines
  - insensitive explosives
- Training
  - training aids
  - man-machine interface
  - leadership
- Logistics and Procurement
  - reliability
  - effectiveness
  - interoperability
  - low cost with quality material
- Life/Medical Sciences
- Environment (air, ocean, land and space)

Discussions with OSD, the military Services, and other government agencies led the Sponsor to select six of these areas for examination at the first ET Workshop. These six areas are not more important to DoD missions than the other seven, which should be considered at a second Workshop at a later time. The six areas chosen: Command, Control and Communications; Mobility; Search and Surveillance/Electronic Warfare; Directed Energy (as applied to SDI); Manufacturing; and Mission Support. At the suggestion of the Sponsor, we divided the Mission Support area into two sub-areas, Human Factors and Biotechnology.

Professor Karl F. Willenbrock from Southern Methodist University, a nationally known engineer well acquainted with DoD needs, served as the overall chairman of the Workshop. For each application area we appointed a session chairman, selected on the basis of current knowledge of the area. Dr. Robert Lontz, Director of the Physics Division at the Army Research Office, was chairman of the Search and Surveillance/ Electronic Warfare session. Dr. Matthew White, a senior scientist with the SDIO office of Innovative Science and Technology, chaired the Directed Energy session. Mr. Albert R. Lubarsky, Director of Long Range Planning in the Office of the Assistant Secretary of Defense for C^3I, oversaw the Command, Control and Communications session. Mr. Raymond Siewert, Director of the Engineering Technology Office in ODUSD (R&AT), chaired the Mobility session. Dr. Vincent J. Russo, Acting Director of the Manufacturing Technology Division at Air Force Wright Aeronautical Laboratory, led the Manufacturing session. Dr. Joseph Zeidner, Research Professor of Public Policy and Behavioral Sciences in the Graduate School of Arts and Sciences at George Washington University and a retired senior scientist with the Department of the Army, conducted the Human Factors session. Captain James Vorosmarti, Jr., USN, Assistant for Medical and Life Sciences R&D to the Under Secretary of Defense for Research and Engineering, oversaw the Biotechnology session. One month prior to the Workshop, the session chairmen met with the Sponsor (DUSD/R&AT) and Sub-Sponsors (NASA and DoE) at SAIC in McLean. Each session chairman was asked to define and scope his area of application, identify candidate session members, and pre-select a set of Delphi responses relevant to his area of application.

To encourage the participation of DoD experts actively engaged in programs relevant to the ET areas of applications, SAIC briefed appropriate Service and agency officials on behalf of the Sponsor. The DUSD (R&AT) then formally invited the Services to nominate session members to represent their constituent interests. Table I.4 identifies the organizations represented by the Workshop attendees. To a large degree, the Workshop session participants were involved in development programs (rather than research). In many cases, this was the first time they had been asked to help identify research areas of direct interest to them.

Each Workshop session was guided by a Protocol approved by the ET Program Sponsor. The Protocol defined "emerging technologies," specified how the panelists were to rank the ETs, and specified how time-of-availability estimates were to be made. The Protocol described each ET as quantitatively as possible and identified related manufacturing know-how required to allow application of the ET. The Protocol described the status of development work and identified milestones that needed to precede application. Participants were asked to identify applications in terms of military use/products/processes, and likely impact (changes to US military capabilities, and synergistic effects upon military capabilities when combined with other technologies).

The participants in each session made an initial selection of about two dozen Delphi technologies that appeared to be of potential importance for their area of application. They then picked a "top half," and then further split the top half into two parts. The top quartile, of highest priority, was to be designated Category "A"; the next quartile was to be designated Category "B"; and the bottom half was to be designated Category "C." Some sessions chose to regroup or rename items from the Delphi Survey. Some sessions added a significant number of new items and identified them as high priority.

1. Command, Control and Communications

The Command, Control and Communications (C^3) session focused on communications technology, automatic data processing hardware, computer languages and software, electronic devices, and the command process. The session began by selecting items from the Delphi-originated list and added other technologies thought by the Workshop participants to be of similarly high interest. The session prioritized the technologies by reference to the following set of characteristics desired in future military systems:

- endurability/survivability of equipment and personnel;
- computer and communications security;
- interoperability;

Table I.4

1985 ET WORKSHOP REPRESENTATION

109 Session Members

OSD (5)

ASD (C^3I)	-	1
SDIO	-	1
USDR&E	-	3

ARMY (20)

ARO	-	1	Army Tank Automotive Command	-	2
DAMA-ARR	-	1	HQ, USACE	-	1
AMMRC	-	1	HQ, USAMRDC	-	2
RDA	-	2	Army Research Institute	-	1
CEC	-	2	NVEOL	-	2
Harry Diamond Laboratories	-	1	Electronic Warfare Lab, Ft. Monmouth	-	1
AMC	-	1	Electronic R&D Command	-	2

NAVY (47)

OPNAV	-	1	NSWC	-	3
NPRDC	-	2	DTNSRDC	-	2
NOSC	-	5	Naval Medical Research Inst.	-	1
ONT	-	4	NTEC	-	1
NWC China Lake	-	3	Naval Air Propulsion Center	-	1
S&NWSC	-	1	ONR	-	6
NRL	-	13	NADC	-	4

AIR FORCE (9)

AFWAL	-	5
Human Resource Laboratory	-	1
AFOSR	-	1
FASC	-	2

Table I.4 (Continued)

AGENCIES (24)

NSA	-	3
DARPA	-	4
NBS	-	11
DCA	-	1
DCEC	-	1
NASA	-	4

OTHER (4)

George Washington University	-	1
CNA	-	1
Sandia National Labs	-	1
University of Michigan	-	1

OBSERVERS (19)

OSTP	-	1	B-K Dynamics	-	1
CIA	-	4	DIA	-	1
DoE	-	1	IDA	-	1
ASME	-	1	NSF	-	1
USDRE	-	2	USD (P)	-	1
NISC	-	1	Eagle Research Group	-	2
USNA	-	1			
NSWC	-	1			

- economy and affordability;
- force multiplication; and
- responsiveness.

Of the emerging technologies this session chose from the Delphi list, about 80% came from four technology categories:

- communications, radar, and signal processing;
- computers;
- electronic materials and devices; and
- robotics, automation, and machine intelligence.

The session's Category "A" (top 25%) selections (with the eight highest-priority ETs listed first) were:

- High-performance battery technology;
- Distributed automatic control of communications networks in hostile environments;
- Automatic generation of software from natural language;
- Parallel processing technology;
- Distributed data processing;
- Ultra-low-loss fiber optics;
- Automated image recognition and classification;
- Speech recognition;

- Design principles to improve reliability of electronic systems;
- Automatic allocation of functions between men and machines;
- Threshold logic for decision making with incomplete information;
- Decision support systems for military decision making;
- Compact high power mm-wave antennas;
- Automatic mapping of signal processing algorithms in high level language into VLSI configuration;
- High-performance A-D and D-A converters; and
- Computer languages appropriate for parallel processing.

2. Directed Energy

The Directed Energy session attempted to identify emerging technologies that could contribute to the development of power supplies for photon and particle beams, or a means for generating, forming, and directing beams. The beams of interest would be suitable for Strategic Defense Initiative (SDI) weapons or for surveillance, acquisition, targeting, and kill assessment (SATKA). The quite different set of emerging technologies that might contribute to the development of kinetic energy weapons were excluded. The participants assumed that while directed energy weapons are not necessary for the success of SDI, directed energy for SATKA is necessary.

The session first eliminated ETs not related to directed energy, ETs that would be covered by other sessions, and "old" technologies that are slowly evolving over time. (The session did not consider these to be true emerging technologies.) Almost all of the technologies the session identified came from the Directed Energy category of the Delphi Survey. Metal matrix composites (#I-6) and coherent gamma ray sources (#J-6) were exceptions.

After some renaming, refining, and refocusing, the session ranked the ETs in the following way:

Category "A" technologies (top 25%):[2]

- Prime power (E, N);
- Metal matrix composites for space structure (E, N);
- Electron beams (E, N, *);
- Artificially structured materials for pulse power switching (E, N); and
- Neutral particle beams (N).

Category "B" technologies (next 25%):

- Coherent locking of laser beams (E);
- Nonlinear phase conjugation techniques (E);
- X-ray lasers--nuclear driven (E, *);
- Short wavelength lasers--non-nuclear (E); and
- Free electron lasers.

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2. Key to notes on emerging Directed Energy technologies:
(E) - Qualifies as an emerging technology
(N) - Necessary for success of SDI
(*) - Discussion at the session was limited by security considerations

3. Manufacturing

For the purposes of identifying relevant emerging technologies, session members defined manufacturing to include the entire process starting with product development, continuing through design and production, and ending with support and maintenance. The session's most important consideration in choosing ETs with application to manufacturing was potential payoff for DoD in terms of cost (life cycle or acquisition), performance, quality (high yield of satisfactory product), flexibility, and responsiveness. The session also considered return on investment; how well a Delphi item fits the definition of an emerging technology; how long it would take for implementation; whether this ET represented a new capability or opportunity and responds to a current need; and whether another session at the Workshop would consider similar applications.

The session's Category "A" technologies for manufacturing (with the three highest priority ETs listed first) were:

- High speed, high capacity computers;
- Advanced sensor development;
- "Intelligent processing" concepts;
- Autonomous machine vision/image recognition;
- Man-machine interactions;
- Manufacturing systems integration;
- Processing of limited/non-error-free data sets;
- Decision support systems; and
- Muscle-like mechanical actuators.

Seventy-five percent of those technologies chosen as high priority (Category "A" or "B") came from three Delphi technology categories:

- computers;
- electronic materials and devices; and
- robotics, automation, and machine intelligence.

The session identified precision engineering, an area not mentioned in the Delphi Surveys, as an important emerging technology. The Manufacturing session suggested strongly that the next ET Workshop should include a session devoted exclusively to emerging technologies in materials.

4. Mission Support - Biotechnology

The Biotechnology session examined a number of technologies that would use biological materials or processes, including technologies that might provide protection against agents of biological and chemical warfare. The session assigned seven technologies to Category "A":

- Sustained release and targeted delivery of materials, e.g. drugs;
- Organisms that could metabolize materials of military interest;
- Organisms that could counter biodegradation of structures;
- Biotechnological means of decontaminating personnel and equipment exposed to CBW agents;
- Prophylactic/therapeutic compounds to counter CBW agents;
- Biologically-based techniques for separating materials; and
- Biologically-based techniques for manufacturing materials.

5. Mission Support - Human Factors

This session examined emerging technologies in manpower and personnel, training and simulation, human factors engineering, and cognitive sciences that might improve human and systems performance to maximize mission readiness and combat performance. In prioritizing the technologies, the session considered:

- impact of the technology vs. risk of development;
- whether the timing of development fits the ET definition; and
- whether the benefits of the technology outweigh the cost of the development.

By design, the Delphi Survey had emphasized hard sciences, not human factors. The session participants therefore added 33 more emerging technologies in education and training, manpower and personnel, simulation and training devices, and human factors engineering to the list of nine technologies (most from robotics, automation, and machine intelligence) they chose from the Delphi Survey. The session divided the list of ETs into two halves, and assigned individuals to write protocols on the top half. The session as a whole evaluated the completed protocols, and then prioritized them. The first quartile included:

- Intelligent computer-aided instruction (D)[3];
- Decision aiding systems (D);
- Image generation/display (N); and
- Performance prediction and assessment (N).

The second quartile of ETs that were selected included:

- Embedded systems for training and job aiding (N);
- Computer-aided design for manpower, personnel, and training (N);
- Realistic combat simulation (N); and
- Remote robotic devices (D).

6. Mobility

The Mobility session considered applications of ETs to surface (land and water) vehicles, and air, undersea, and space transport. They looked specifically for technologies that promise to increase capability and survivability, improve availability, and reduce costs.

The session's 12 Category "A" technologies were:

- Advanced engine technology;
- Engines with low IR signatures;
- Fuel cells for vehicle propulsion;
- Reduced observables;
- Active control of sound;
- High temperature non-metallic materials--novel processing methods;
- Automatic vision systems;
- Man machine interface;
- Automated speech understanding;
- Robotic task manipulators;
- Control of vortex flow in air and under water; and
- Supersonic combustion for high mach number air breathing propulsion.

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3. Key to Human Factors technologies:
(D) - ET identified in Delphi survey
(N) - ET newly identified at the Workshop

Eighty-five percent of this session's high-priority technologies fell into one of four technological areas:

- combustion, propulsion and energy;
- fluid dynamics;
- macroscopic materials; and
- robotics, automation, and machine intelligence.

7. Search and Surveillance/Electronic Warfare

The session on Search and Surveillance/Electronic Warfare (S&S/EW) examined its subject from three different perspectives: (1) escalation of conflict, with measures, countermeasures, and counter-countermeasures; (2) examination of the carrier or medium, looking at both acoustic and electromagnetic radiation; and (3) targeting, here understood to include search, detection, identification, tracking, and fire control. Criteria for initial selection of ETs were: confirmation that the listed item represents an actual technology, and not just a requirement; that it is currently moving forward in research and development; and that this technology is directly related to S&S/EW.

The top 25% of the ETs chosen by the Search and Surveillance/Electronic Warfare session (with the five highest priority ETs listed first) were:

- High performance A/D conversion for recording and signal processing (e.g., 16 bits - 5 MHz; 8 bits - 50 MHz);
- Technologies associated with reduced signature military platforms;
- Integrated optical sensors/analog/digital processing elements in a single chip focal plane array;
- Growth of three- and four-component compound semiconductors of desired (specified) characteristics;
- Image recognition and artificial intelligence;

- Framework for modular signal processors;
- Multi-signature decoys;
- Active control of sound;
- Melding of best features of digital and analog computing, including optical processing to get extremely high computation rates on many parallel channels;
- Heterostructure superlattices of layered materials;
- High density, two-dimensional, solid-state arrays for imaging in the visible and infrared;

- Optical fiber technology;
- Optimum allocation of decisions and actions between humans and machines;
- Highly parallel architecture based on systolic chips;
- Monolithic GaAs and III-V related components;
- Fast-wave amplifiers as efficient high power sources of coherent millimeter and sub-millimeter wave radiation;
- Low-probability of intercept (LPI) and long range air frame classification radar for airborne intercept;
- Chemical bonding agents; and
- High speed computers--parallel and array processors in compact portable modules.

Eighty-five percent of the ETs selected by this session came from four technology categories:

- communications, radar, and signal processing;
- computers;
- electronic materials and devices; and
- robotics, automation, and machine intelligence.

8. Workshop Conclusions

There was substantial overlap among the technologies assigned high priority by the Command, Control and Communications; Manufacturing; and Search and Surveillance/ Electronic Warfare sessions. All three of these sessions chose 10 of the ETs. Two of these three sessions agreed on 32 additional ETs. "Robotics, automation and machine intelligence" was the most widely chosen of all the subject areas: 20 of the 21 Delphi-identified items in this category were chosen by one or more sessions, with 16 chosen as high priority ETs. Nearly half (nine) were chosen by more than one session.

Two of the technology areas, on the other hand, prompted little interest among the seven sessions at the Workshop. Only two of the 12 Delphi items in chemistry and catalysis were chosen as high priority ETs. In remote sensing, oceanography, and meteorology, two of 25 items were chosen by the initial set of Workshop sessions. (The Sponsor chose not to address environmental ETs at this initial Workshop, due to the breadth of topics in this area. A separate Workshop on Environmental Sciences was held at NRL in November 1985. The results of this Workshop are provided and assessed at Volume III of this Integration Report.) Table I.5 summarizes the interest expressed by the seven Annapolis Workshop sessions in each technology category.

Table I.5

DELPHI TECHNOLOGY CATEGORIES WITH HIGH CONCENTRATION OF TOP PRIORITY ETS

	MISSION AREAS					
DELPHI CATEGORIES	C^3	DE	Mfg.	Mission Support (Biomed & Human Factors)	Mobil.	S&S/ EW
Biotechnology				X		
Chemistry and Catalysis						
Combustion					X	
Communications	X				X	
Computers	X		X			X
Directed Energy		X				
Electronics	X		X			X
Fluid Dynamics					X	
Materials					X	
Optics/Lasers			X			
Remote Sensing						
Robotics	X		X	X	X	X

The marks indicate which Workshop sessions chose at least five items from the indicated Delphi category as high priority ETs.

The various sessions had differing expectations of when the emerging technologies were likely to be included in a product or process. Table I.6 summarizes the average availability date each session estimated for its highest priority ("A"--top 25%) technologies.

Table I.6

AVERAGE AVAILABILITY DATA FOR HIGHEST PRIORITY ("A") ETS OF EACH SESSION

(Calculated from the information in the Workshop protocols)

1990	-	Mission Support--Biomedical Technologies
1991	-	Search and Surveillance/Electronic Warfare
1992	-	Command, Control and Communications
1994	-	Mobility
1996	-	Mission Support--Human Factors
1996	-	Manufacturing
1999	-	Directed Energy

D. SYNTHESIS OF THE SURVEY AND WORKSHOP RESULTS

In this section, we synthesize the results of the Delphi Surveys and Workshop sessions to identify an initial set of candidate topics to study in greater depth. These in-depth studies will provide up-to-date information on which OSD can base policy decisions, such as new technology base initiatives.

In this effort, we are focusing on the earliest portions of the Research, Development, and Acquisition cycle, where the outcomes are the most speculative, but also possess the potential for very high "payoff." These activities, usually funded out of the Technology Base Programs budget categories 6.1 and 6.2, take place at the interface between the military establishment and the innovators in academia and industry. Because the DoD is a minority investor in these activities, an attempt to support decisions must make special efforts to consider research supported by all federal agencies and by private funds. The ET Delphi Survey therefore was an attempt to bridge gaps between the DoD and non-DoD research communities.

The Defense Science Board (DSB) made a similar attempt to bridge this gap in its 1981 Summer Study on the technology base. They sought technology advances that might make an "order of magnitude" difference in military capabilities. They considered candidate technologies in the context of a group of "integrating factors" that appeared to them to permeate scenarios for future wars:

- Sustained Operations;
- Continuous Threat Location/Track;
- Real-Time Information Management;
- Counter Threat Target Acquisition;
- Integrate "Eyeball and Trigger";
- Secure, Jam-Resistant, Mobile Communications;
- Dispersed, Small Units;
- Transparent Complexity;
- Equipment Availability/Reliability; and
- Operations in Extreme Environments.

The DSB report developed a set of "technical requirements" from the scenarios, further along the RDT&E cycle than the research investments we consider here. On the basis of the two sets of criteria, the DSB panel identified the following list of "order of magnitude" technologies:

- Very High Speed Integrated Circuits;
- Stealth;
- Advanced Software/Algorithm Development;
- Microprocessor-Based Personal Learning Aids;
- Fail-Soft/Fault Tolerant Electronics;
- Rapid Solidification Technology;
- Machine Intelligence
- Supercomputers;
- Advanced Composites;
- High Density Monolithic Focal Plane Arrays;
- Radiation Hardened Advanced Electronics;
- Space Nuclear Power;
- High Power Microwave Generators;
- Large Space Structures;
- Optoelectronics;
- Space Based Radar; and
- Short Wavelength Lasers.

Several of these categories contain technologies identified in the ET Delphi Surveys that were chosen by Workshop participants as of especially high priority.

In synthesizing the work of the Delphi Survey participants and Workshop panelists, and in considering technologies that are candidates for in-depth studies, we found it convenient to group technologies into "emerging technology aggregates." Each aggregate represents a "significant" area of technology with promise of wide and important applications. On the other hand, the aggregates are small enough, with sufficient commonality among items, that the area is amenable to detailed technical analysis by a relatively homogeneous group of experts. Table I.7 lists the candidate sets of technology aggregates, selected to serve as possible topics for in-depth study. Each of these ET aggregates is described in some detail in the remainder of this Executive Summary.

Table I.7

HIGH-PRIORITY EMERGING TECHNOLOGY AGGREGATES

Computer Parallel Processing Technology
Robotic Vision, Image Recognition and Classification
Decision Logic and Allocation, with Man-Machine Interaction
High Temperature Structural Materials
Portable Power Supplies
Speech Recognition and Natural Language Understanding
Electrooptic Technology
Advanced Software Generation
Signal Processing Technology
Non-silicon Electronic Materials and Optoelectronics
Reduced Signature Technology
Advanced Engine Technology
Biologically Based Processes
Simulation Technology and Training

Computer Parallel Processing Technology

The Delphi Survey produced five individual technology submissions addressing different proposed hardware embodiments of highly parallel computer processing, and one submission regarding development of computer languages appropriate to parallel processing. The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(E-2)[4]	Parallel processing based on optical communication between N processors and M memories (not necessarily chip-to-chip optical interconnections)
(E-3)	Parallel processing based on novel interconnect hard wired (non-optical) schemes (e.g., "cosmic cube" architecture)
(E-4)	Architecture analogous to neuron connectivity in mammalian brains
(E-6)	Highly parallel architecture based on systolic chips
(E-7)	Computer language which is really appropriate for parallel processing
(E-14)	Melding of best features of digital and analog computing, including optical processing, to get extremely high computation rates, with appropriate dynamic range, on many parallel channels

Almost all of these were chosen by one or more Workshop sessions as being of high priority.

Members of the computer R&D community generally agree that, barring the discovery of fundamentally different and as-yet-undemonstrated hardware technology, the rapid advances in instruction execution rates that we have witnessed for the past few decades are going to slow down precipitously. The only known technology that possibly might make orders of magnitude advances in throughput is highly parallel processing. There are also situations in which parallel processing is desirable because input data come from many nodes at once. Several approaches to highly parallel processing have been suggested. This is an actively developing field, clearly on the verge of emerging, in one or more forms, into serious applications.

Research that falls within this category and needs further investigation to support the technology development includes: very wide band multiplexing; efficient algorithm;

4. The numbers in parentheses are the identification numbers for the 237 Delphi-identified ETs. For the complete list, see Appendix 6.

rapid synchronization of CPU's (improvement of at least an order of magnitude over present systems); large I/O capability to and from distributed memory sites; and general algorithms for problem subdivision (partitioning algorithms).

In the protocols developed at the Workshop, the following uses for parallel processing were identified by members of the Command, Control and Communications; Search and Surveillance/Electronic Warfare; and Manufacturing sessions:

- Command, control and communications for complex systems (e.g., SDI);
- Data base management systems;
- Decision making and forecasting (e.g., weather forecasting);
- Unit processes, CAD/CAM, advanced manufacturing systems; and
- Signal processing and pattern recognition.

Robotic Vision, Image Recognition and Classification

Five of the Workshop sessions identified this major area. The range of technologies represented here could potentially make an order of magnitude difference in present combat system effectiveness or could provide entirely new options for addressing current or future defense missions. This finding is consistent with the 1981 DSB study which identified "Machine Intelligence" as one of the 17 "order of magnitude" technologies.

The three Delphi-identified technologies that address this area are:

Delphi #	Technology
(L-1)	Automated image recognition and classification through use of AI techniques
(L-2)	Vision for robotic systems
(L-3)	Autonomous weapons vision with automatic target recognition

Developments needed before these technologies can fully emerge range from some that are likely to be available within several years, like an order of magnitude increase in computer performance, to significantly more reliable algorithms, development of which cannot be scheduled with any confidence.

The Workshop identified the following categories of important potential military application:

- super smart weapons;
- battlefield management;
- surveillance and reconnaissance;
- industrial automation; and
- remote sensing with real time analysis.

Another potential application of great importance is in inspection systems for a host of low and high technology industries.

Decision Logic and Allocation, with Man-Machine Interaction

Five of the seven Workshop sessions chose emerging technologies from this category. The five Delphi-identified technologies that address this area are:

Delphi #	Technology
(L-4)	Optimum allocation of decisions and actions between humans and machines in a man-machine system
(L-16)	Threshold logic for decision making in situations of incomplete information
(L-17)	Decision support system for military decision making (e.g., for efficient task assignment and efficient procurement procedures: user-friendly; information storage; retrieval; processing and display to support decision making)
(L-18)	CAD/CAM-type systems with prediction models of human performance
(L-19)	Man-machine mutual monitoring loops

The Workshop participants identified additional emerging technologies in this category that they thought would be important in their application areas. These included:

- Electroencephalographic (EEG) sensors ior monitoring alertness of operators;
- Data processing--high volume, high speed (100 MIPS) filtering and manipulating;
- Data transmission--local area networks ($\sim 10^8$ Hz), transport and control protocols;
- Displays--large screen displays with resolutions 2000 x 2000 lines or better;

- Improved data correlation--algorithms to correlate/associate better data from diverse sources;
- Knowledge-based systems--AI techniques for higher levels of automation;
- Large-scale data bases, and distributed data base management--distributed operating systems, data base access, queries, and updates involving different data bases;
- Generic expert system building tools;
- Interactive human-computer interface that allows efficient dialogue; and
- Decision methodology for optimal system architecture to retain overall system property of human reasonableness and reversibility, with the machine component accounting for limitations in human capacity or stress tolerance.

Decision aiding and allocation are important in any large scale enterprise, commercial or military, for example: corporate planning and management; production scheduling; intelligence analysis; forecasting; and relieving the information overload faced by military commanders. Optimum allocation of decisions between man and machines could reduce training requirements for personnel and reduce the probability of human errors. The Workshop participants also expected these technologies to play an important role in developing modern command centers, automated cockpits, and safer nuclear reactors.

High Temperature Structural Materials

New alloys promise enhanced performance in a number of areas, including: superior corrosion resistance; high strength, particularly at elevated temperatures; increased wear resistance; better oxidation resistance; and reduced critical material content. Delphi Survey participants rated the value of these technologies high (all threes and fours on the Survey scale) and several of the Workshop sessions strongly agreed.

The seven Delphi-identified technologies that address this area are:

Delphi #	Technology
(I-3)	Fiber-reinforced ceramics for high-strength applications at high temperatures
(I-6)	Metal matrix composites for high strength-to-weight
(I-9)	Novel methods of preparation of large single or polycrystalline materials, usually prepared as ceramics, such as SiC, AlN, etc.
(I-12)	High temperature ceramics that are tough, durable, and impact resistant

(I-16)	Inorganic polymer systems for high temperature structural applications
(I-17)	Oxidation resistant lightweight composites for performance above 3000°F
(I-20)	Chemical approaches to formation of high purity, crack resistant ceramics

New high-performance polymers are also expected to play an important role in electronic materials processing and also as structural materials.

Developments needed to help these technologies emerge include better understanding of bonding mechanisms and the role of interfaces of dissimilar materials; improvement in fracture toughness; reduction in cost (particularly on a mass production basis); control of grain boundaries; and identification of fiber-matrix materials capable of withstanding very high temperatures.

Workshop and Delphi participants suggested specific applications for these new materials that include:

- high temperature gas turbines and adiabatic diesels;
- lightweight components for missiles, rockets, aircraft, spacecraft. guns, and furnace lines;
- hypersonic aircraft;
- "throw-away" high performance engines;
- SDI and space station components; and
- high temperature chemical processing lines.

Portable Power Supplies

Portable power supplies are important to many military operations, including those considered by the Workshop sessions on Command, Control and Communications; Search and Surveillance; Directed Energy; and Mobility.

The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(C-16)	Long-lived batteries for space applications
(C-17)	High power, high energy density batteries
(C-18)	Efficient, inexpensive fuel cells
(C-19)	Efficient, inexpensive photovoltaic cells

(I-10) Conducting polymers for "all-plastic" batteries and lightweight electronics

(N-3) Prime power

Promising, high-importance applications identified by the Workshop sessions include:

- High-performance power (primary and secondary) for satellites;
- Air-dropped and submarine-launched buoys;
- Longer-life, higher-performance electronic systems for undersea surveillance, arctic warfare, and space operations; and
- 100 megawatt, gigaJoule energy sources for SDI platforms.

In addition to their applications in batteries, the Workshop sessions identified conductive polymers as promising as lightweight, rugged, flexible shields and conductors that might prove useful in radar signature reduction.

Speech Recognition and Natural Language Understanding

Five out of seven Workshop sessions chose speech recognition and natural language understanding as a high priority ET. The two Delphi-identified technologies that address this area are:

Delphi #	Technology
(L-6)	Automatic understanding of speech of a specific individual
(L-7)	Automatic understanding of speech of a general class of individuals

These two technologies were grouped on the basis of their common root in artificial intelligence research and their somewhat similar range of applications, but face somewhat different milestones in their development for further applications.

Speech systems with a limited vocabulary, requiring clear pauses between words, and tied to a single speaker are available today. Speaker-independent systems with large vocabularies, capable of dealing with continuous speech, will require advances in hardware, software, and linguistics, including:

- custom VLSI chips to obtain the computational speeds required (100x improvement in computer power);
- faster search algorithms (10x improvement in algorithms);

- increase in knowledge of invariant relations among linguistic features;
- codification and utilization of constraints imposed by the sound patterns of a language; and
- utilization of the context of knowledge of the subject of discourse in interpreting the sound.

Natural language understanding (NLU) systems with limited domain, some errors, some training and some verification have already been built, but are very limited in scope. NLU systems, which might have speech understanding systems as front ends in many applications, will need to improve significantly in all the following areas before rooting application begins to have significant impact on military capability:

- the size of the domain of discourse;
- the frequency of misinterpretation;
- the level of training required of users; and
- the level of interactive verification of understanding that is required.

Workshop participants identified the following applications as likely to increase significantly military efficiency and capability:

- speech typewriters;
- control-less cockpits;
- verbally-instructed remote/robotic devices;
- military management systems that operate with substantially less clerical manpower and improved efficiency; and
- remotely operated robotic devices that operate in environments hazardous to humans, giving the US military an important tactical advantage by broadening the range of environments that can be penetrated for military purposes.

Electrooptic Technology

This area is of major importance in telecommunications, large scale computing, and other applications where metallic wires are used and limit performance. The use of fiber optics and optical processing elements, envisioned in all major SDI system proposals, will reduce weight and provide the wide band of frequencies needed to perform some demanding tasks. Over the next 10 to 20 years, hybrid systems that combine optics and microelectronics on a single chip will come to be used in many systems. All optical systems will eventually be used for many applications.

The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(J-1)	Ultra-low-loss fiber optics
(J-3)	Optical fiber sensors for measurement of physical parameters
(J-4)	Optical fiber sensors for measurement of chemical properties
(J-11)	Mid- and far-infrared optical fibers of low loss
(G-4)	Integrated optical sensors/digital processing elements in a single chip focal plane array
(N-2)	Advanced communications switching techniques

Applications of these technologies range the full gamut of defense and commercial information systems. These include SDI applications related to C^3I (as mentioned previously), factory-of-the-future applications, most telecommunications systems, remote sensing, and real-time processing at remote locations. The need for secure communication systems with electromagnetic pulse (EMP) protection also plays a key role in driving this technology.

Advanced Software Generation

The ultimate goal of computer technology is to extend and enhance man's capabilities. An important bottleneck has been and promises to be software generation.

The Delphi-identified technology that addresses this area is:

Delphi #	Technology
(E-1)	Automatic generation of software from "natural language"

Other areas relevant to the advancement of software technology include programming methodology, performing measurement, and algorithms/theory. The complexity of defense systems creates a particularly acute need for prediction and verification of software performance.

Signal Processing Technology

Development of more useful systems for performing situation assessment, signal interpretation, information fusion, and generation of plans based on information gathered in real time awaits the emergence of some fundamental improvements in signal processing technology.

The four Delphi-identified technologies that address this area are:

Delphi #	Technology
(D-3)	Automatic mapping of signal processing algorithms described in high level language onto specific multiprocessor architecture or VLSI configurations
(D-6)	High performance A/D conversion for recording and signal processing (e.g., 16 bits-5 MHz; 8 bits-50 MHz)
(D-7)	Coherent signal processing systems for active/passive spatially dispersed sets of sensors
(D-11)	Low-cost, high speed A-D/D-A with built-in filtering

Applications of these technologies include all major strategic and tactical weapon systems and could have a major effect upon any SDI concept.

Non-silicon Electronic Materials and Optoelectronics

New and improved electronics materials are essential building blocks to many new DoD options needed to leverage US technological advantage over potential adversaries. While most of today's electronic systems are based on silicon technology, many think that new materials, particularly the III-V compound family, are the materials of the future. The Japanese have made significant progress and will continue to strive to gain in this area, as was noted by the JTECH Opto-microelectronics panel. The Soviets seem to have given up any major efforts in silicon research, focusing most of their advanced electronic work on III-V materials. (This is discussed in the 1984 FASAC report on Soviet Microelectronics which is being updated by a new FASAC panel in 1987.) The recent advances in high temperature superconductor research may lead to revolutionary developments in electronic materials and optoelectronics. Not having abandoned their Josephson junction work, the Japanese might be poised to take an early lead in this area.

The eight Delphi-identified technologies that address this area are:

Delphi #	Technology
(G-1)	Synthetic nonlinear optics materials custom-designed for specific applications (e.g., optical computer elements)
(G-3)	Molecular-scale electronic circuit elements and conductors
(G-4)	Integrated optical sensors/digital processing elements in a single chip focal plane array
(G-6)	Growth of three- and four-component compound semiconductors of desired (specified) characteristics
(G-12)	Bulk crystal growth of GaAs, other III-Vs, and semiconductor alloys
(G-14)	Heterostructure superlattices of layered materials
(G-19)	Optical read/write recording devices
(I-1)	Conducting polymers for "all plastic" batteries and lightweight electronics

In addition, new polymeric materials are expected to play an important role in these technologies, particularly in providing improved substrate materials.

Expected developments based on these technologies which include almost any defense system that could benefit from higher-speed or higher-frequency electronics, are very numerous. The time frames in which these components might become available for application in defense systems range from 1986 (mass-produced GaAs or Josephson junction IC chips) to the year 2000 and beyond (molecular-scale electronics).

Reduced Signature Technology

Reducing signatures of military platforms at all frequencies is a high-priority goal of US military developers because reduction of radar, IR, and acoustic cross sections can significantly improve US military capabilities.

The nine Delphi-identified technologies that address this area are:

Delphi #	Technology
(C-9)	Aircraft engines with low infrared emissions
(D-12)	Multi-signature decoys (including visual holograms)
(D-13)	Active control of radar cross sections

(D-14)	Materials with reduced radar and IR signatures
(D-15)	Antennas with low radar cross sections
(D-16)	Air vehicles with very low observable signatures through multidisciplinary technology integration
(D-18)	Active control of radiated sound
(D-19)	Active control of reflected sound (target strength)
(N-21)	Low-probability-of-intercept (LPI) long range air frame

The above topics have had ongoing active research programs for several years, but much more is needed to fully utilize these phenomena, particularly under varying conditions at diverse electromagnetic frequencies. Advanced technologies for reducing acoustic signals are in their infancy, but could have major military impact. Improved recognition of decoys from our adversaries and development of better US decoys may also be possible with several of the emerging technologies identified in this study. Arrangements of materials whose temperature (IR signature) can be tailored are particularly important, e.g., thermoelectrics.

Advanced Engine Technology

Research on near-adiabatic engine technology has as its goals, reduction of cooling system requirements, compactness, and improved fuel economy, reliability/maintainability, and survivability.

The three Delphi-identified technologies that address this area are:

Delphi #	Technology
(C-2)	Spark-ignited diesel engines, usable with a wide spectrum of fuels
(C-3)	Near-adiabatic diesel engines utilizing high-temperature ceramic components (and no circulating coolant)
(C-10)	Stable high-temperature lubricants for near-adiabatic diesel engines

Fuel availability of these technologies is dependent on: research in high temperature materials; high temperature friction and wear phenomena; unconventional lubrication techniques (including solid lubricants--both in slurry and surface coating form); and near isothermal heat transfer phenomena. Milestones in the development of this technology for production and use include: improved processing of ceramic and composite materials; improved and more reliable component NDE inspection techniques; methods of reducing high temperature material costs; methods of producing high-temperature slurries in a repeatable and economically feasible manner; and improved advanced materials analysis methods.

Adiabatic diesel engine technologies identified by the Delphi respondents were picked up by the Mobility session, and recognized as promising qualitative improvement in ground, naval, and air vehicles in terms of compactness, fuel economy, weight reduction, signature reduction, multifuel characteristics, and design flexibility. Not included here but clearly important to advanced engine technology are materials problems, e.g., development of ceramic engines. This will be covered in a subsequent ET Workshop.

Biologically Based Processes

This aggregation of ETs includes a variety of processes and techniques. All exploit in one way or another the extraordinary specificity and versatility of biological processes.

The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(A-5)	Development of organisms that will metabolize militarily relevant toxic waste products
(A-6)	Development of organisms that will counter the biodegradation of materials
(A-7)	Bioprocess technology for materials
(B-5)	Bio-catalysis with immobilized enzymes
(B-9)	Enzyme catalysts that work in non-aqueous environments
(N-3)	Biologically based materials separation techniques

Potential military applications of these ETs include new ways to detect or counter enemy chemical or biological warfare agents, new means to make or extract high-value materials of military importance, and new ways to protect military systems and structures against the ravages of nature.

DoD and other developers have had less time to think about applications of biotechnology than they have had to think about other more evolutionary ETs. It is likely that there will be other military applications that no one has yet suggested, that will prove to be as important as the ones identified in this study.

Simulation Technology and Training

Simulation technologies, which are basically hardware and can be discussed on the basis of technical characteristics, were identified as important by the Delphi Survey. These hardware technologies can support development of important systems of training technology that were examined closely at the Workshop.

The five Delphi-identified technologies that address this area are:

Delphi #	Technology
(N-12)	Intelligent computer-aided instruction
(N-13)	Image generation/display
(N-14)	Cognitive abilities/aptitude measurement and performance prediction/assessment
(N-15)	Embedded systems for training and job aiding
(N-17)	Combat environment simulation technology

In considering the importance of these technologies, it is useful to distinguish three categories of application: combat simulation; "classroom" education enhancement; and embedded system training.

New technologies can provide realistic simulations of combat environments for training and for testing of individual skill proficiency and operational capability. They promise to improve combat effectiveness and greatly reduce training costs. High fidelity simulations, which should be most effective, could be realized by 1990. The subset of these technologies that received the most attention at the ET Workshop was interactive image generation/display. Inexpensive on-line techniques are needed to provide wide angle, high brightness, high contrast, high resolution visual presentations in simulators, with high scene detail at close range and dynamically changing visual content caused by object motion or surface effects and realistic response to sensor input. Four technologies that show promise are: helmet-mounted displays (using laser projectors, fiber optics, or miniature CRTs); area of interest high-resolution inserts or variable acuity lenses; high intensity color projectors; and hybrid simulations based on computer generated/synthesized imagery (CGSI) or on cell texturing.

The second group of training-related ETs aim at reducing the cost and increasing the effectiveness of a wide range of training and education programs. AI based computer instruction could increase the efficiency of training by relieving human instructors of tasks that machines can perform well, effectively increasing instructor/student ratios. Expert systems that emulate a subject matter expert with extensive knowledge domain, students whose knowledge becomes progressively less primitive, and tutors who follow good instructional principles will be needed if the anticipated benefits are to be realized. Workshop participants thought that such expert systems were 15 years away, but the estimate is probably needlessly pessimistic.

The third set of technologies in this group, embedded on-line training and performance testing in all military systems, would overcome some important drawbacks of school-based training, including constraints on frequency and duration of schooling because of cost and manpower losses. Embedded training technology has already been demonstrated in many computer systems and by 1988 should be available for incorporation in military systems.

Summary

The preceding synthesis identified 14 ET aggregates as an initial set of candidate priority topics for in-depth studies.

Table I.8 is a rough breakdown of the application areas for each of the ET aggregates, based on information in Delphi Survey responses and Workshop protocols.

E. EVALUATION OF EMERGING TECHNOLOGIES PROGRAM EXPERIENCE TO DATE

The Emerging Technologies Program is intended to assist the DUSD (R&AT) in developing a coherent Department of Defense strategy for technology base investment, by identifying rapidly advancing/emerging technologies of potential importance to national security. The program has four repeatable phases:

Table I.8

APPLICATIONS OF ET AGGREGATES

Aggregates	Intelligence	Communications	SDI	Search & Surveillance	ASW	Radar/Microwave	Operations-manpower issues	Mobility (Vehicles)	Stealth	Power storage & transmission	Structures	Industrial processes	Chemical warfare	Weapons	Warfighting
1. Computer parallel processing	X	X	X	X	X		X	X				X			X
2. Robotic vision, image recognition	X		X	X				X				X	X	X	X
3. Decision allocation, man-machine interaction	X		X				X	X				X			X
4. High temperature structural materials			X					X			X		X		
5. Portable power supplies	X	X	X					X		X					
6. Speech recognition, natural language understanding	X	X					X	X				X			X
7. Electrooptics	X	X	X	X		X			X			X		X	X
8. Advanced software generation	X	X	X	X			X					X			X
9. Signal processing		X	X		X	X			X						
10. Non-silicon electronic and optoelectronics		X	X	X								X			X
11. Reduced signature technologies	X		X	X	X	X			X					X	X
12. Advanced engine technology								X							
13. Biologically based processes											X	X	X		
14. Simulation and training				X			X	X							X

(1) A three-round Delphi Survey of 100 nationally recognized technical experts to identify and characterize important emerging technologies;

(2) A Workshop attended by 120 DoD application experts, to review the emerging technologies identified by the Delphi experts and protect the likely impact of the emerging technologies on future military capabilities;

(3) Integration of the products of items (1) and (2) by SAIC into a detailed assessment report, adding inputs from SAIC's foreign technical assessment activities, and in-house technology expertise where appropriate; and

(4) A series of in-depth assessment panels with topics chosen by DoD after study of the product of Item (3) to examine in detail high priority "ET aggregates" in terms of technological risk, cost/benefit ratios, vulnerability issues, synergisms of ETs, and the like.

Several approaches to each of the above phases--and indeed, different phases--could have been chosen. The paragraphs that follow discuss these choices in light of initial experience.

The 1985 Delphi Effort

To obtain initially a "world view" unconstrained by organization preferences, an initial list was prepared of over 200 nationally eminent technical experts, from which were chosen candidates to participate in the three-round ET Delphi. This list was culled to avoid unnecessary duplication of expertise and the remaining 130 candidates were asked to participate; 102 accepted. Practical contraints, including time and budget limitations, did not permit use of the thousands of experts whose knowledge might permit an encyclopedic treatment of emerging technologies. Emphasis in the first phase was upon breadth rather than depth; in the fourth phase of the ET Program, the in-depth assessments emphasize depth by concentrating on those ET aggregates of highest importance.

Most of the Delphi respondents are immediately recognizable authorities in their field. The vast majority of these experts work outside Government. This was a purposeful selection, to reduce the possibility that the participants' programmatic interests might skew the identification of emerging technologies in the Delphi Survey. Also, the respondents were asked to address only those technology areas in which they considered themselves to be competent.

This approach proved manageable. The Delphi "Test Group" identified 65 ETs in the initial round. The larger group of Second Round respondents increased the number of ETs to be considered by the Workshop to 237.

The 1985 ET Workshop

A major point of discussion relative to the Workshop was the advantages and disadvantages of classified sessions. Because classification would have affected adversely the range of attendees, because an appropriate lowest common denominator of clearance would have been difficult to agree upon, and because the "need to know" principle would have severely restricted the breadth of discussion groups, SAIC recommended, and the Sponsor approved, an unclassified Workshop forum.

In choosing participants for the 1985 ET Workshop, care was taken to try to balance membership, so as to minimize the effects of the participants' predispositions on what would ideally be objective deliberations. Nonetheless, when 128 DoD experts were convened, representing various Service, laboratory and headquarters constituencies, coalitions of interests were expressed. This was not unexpected. Also, the interests of Services/laboratories/headquarters that decided not to participate fully were not fairly represented. For future Workshops, SAIC recommends that parallel "bottom up" solicitation of attendees from the Services, etc., and official requests from OSD to the participating parent organizations be used again. This membership selection process should be given ample time to allow the most representative attendance possible.

In 1985 two rounds of the Delphi Survey were completed prior to the Workshop. In future iterations, Delphi Rounds One, Two and Three should be completed prior to the Workshop, by beginning the survey well in advance, i.e. four months or more before the Workshop. A fourth round of the Delphi Survey should be conducted after the Workshop so that a concluding "Declarative" Round can address Workshop results.

This process resulted in the production of a very large amount of data for DoD consideration, accrued in a short period of time. In the future we should lengthen the schedule delivery of all Delphi data to the Workshop session Chairmen and participants, in advance of the Workshop, so that they can have more opportunity to absorb and address these complex technology issues before the few days of the Workshop. We should also expand the Delphi inputs when necessary to include adequate descriptions of all ETs being cited and to cull out Delphi submissions that represent "wishes," and not emerging technologies.

The 1985 ET Survey and Workshop succeeded, applying a DoD "filter" to a broad menu provided by outside experts. High priority ETs identified by both the Delphi Survey and the Workshop have formed a sound basis for identifying candidate ET Aggregates as topics both for follow-on in-depth assessment panels and for future ET Workshop sessions.

F. PLANS FOR 1987 AND BEYOND

The analyses and assessments included in this Report are a synthesis of the *initial* examples of the first three phases of the ET Program: Delphi Survey; Workshop; and Integration. Fourth phase activities consist of Sponsor-directed in-depth assessments of the highest priority ET Aggregates. The ET Program is structured as a repeatable process, to address promising areas for potential investment that could not be included in the initial activities, as well as new areas yet to be identified. All four phases can be repeated, in full or in portions tailored to specific requirements.

Major benefits to the Sponsor should result from the products of Phase Four of the ET Program--reports by the In-Depth Assessment Panels. Two such Assessment Panels have been commissioned by the Sponsor to date; a series of ET Assessment Panels is *planned.*

Each ET Assessment Panel will review in depth the world state of the are in the selected ET Aggregate, identify key milestones/breakthroughs needed to support the Workshop-identified DoD applications, and provide options and recommendations for follow-on DoD/intelligence community actions. Panelists will be instructed to identify ETs that should receive increased/accelerated research investment and to explain the importance of pursuing this investment strategy. They will be asked to identify and assess technological risks and likely costs of each ET, as well as its projected benefits. Panelists will examine the likely relation of timing to success of the investment, the other technological advances that must precede the development of the ET of interest, and any likely synergisms with other ETs. Table I.9 indicates in more detail the expected contents of an ET Assessment Panel report.

Table I.9

REPRESENTATIVE DETAILED CONTENTS OF AN IN-DEPTH ET ASSESSMENT

- Assess and describe research activities (including principal areas of emphasis) and the current state of the art achieved world-wide in the topical areas spanning the selected ET Aggregates.
- Identify the institutions and research teams here and abroad that are doing the most significant research from a technical, not quantitative, standpoint.
- Compare US state of the art with its major competitors, including the Soviet Union, by assessing trends in the level and intensity of effort (growing or waning); novel research approaches and techniques; and, degree of access to research instrumentation, e.g., computers.
- Extrapolate from current state of the art those furture emerging technologies and applications that might have high military, economic or policitcal impact, including considerations of technology transfer.
- Identify the milestones or subsequent achievements that can be expected in future research as checkpoints for later monitoring of progress in the field. Identify the most probable research teams achieving this result.
- Assess the impact and implications of US research accomplishments versus those accomplishments occurring in the Soviet Union.
- Identify areas of research in which there is an anomalous absence of work in the technical literature here or in countries giving the United States its major competition.
- Identify the funding agencies sponsoring this work in the United States, and estimate the level of effort.
- What is currently not being done to ensure the timely US pursuit of research necessary to produce a desired ET (specifics, by sub-topics).
- Identify areas of research which are outside the ET Assessment Panel's focus, but which might be important for a future panel to address (e.g., serendipitous findings).

It is expected that the in-depth assessment reports will make a major contribution toward coherent OSD-directed efforts to identify rapidly advancing technologies. Selection of topics for the assessments will be soundly based, taking into account inputs from: outside experts (Delphi Survey); DoD applications requirements (Workshop Protocols); other relevant experience (SAIC technology assessments); and this SAIC Integration Report effort. The in-depth assessments will be kept responsive to DoD near-term needs by careful selection of the chairmen and panelists, and on-going guidance from DUSD (R&AT).

It is also recommended that a new Delphi Survey be commissioned in 1988, to ensure that no new technologies will be missed and to provide a continuous screening of the culled emerging technologies. By carefully tracking the progress of ETs, one can maintain credibility in the process via constant "self-checks."

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CHAPTER II

OVERVIEW OF THE EMERGING TECHNOLOGIES PROGRAM

A. BACKGROUND

Since World War II it has been the policy of the US Government that the United States be in the forefront of scientific and engineering research. Coupled with the leadership in research has been the anticipation that first in research also implies first in application of the research results. Key to that transfer of research results is innovation. A major ingredient in that innovative process is to identify as early as possible emerging and rapidly advancing technologies. This is essential if the United States is to maintain its technological competitive edge. The rise of fierce foreign competition in both the defense and commercial markets makes it clear that technological leadership will rise or fall on the ability of the United States to maximally utilize (faster than its competition) its $14.5 billion (1984) investment in basic research.[1] From a defense point of view, only a small fraction (see Figure II-1) is directly sponsored by the DoD. This is not only true for basic research but is also germane to applied research. Current budgetary trends continue to decrease the DoD research investment contribution.

For a decade or so after World War II, the United States had few worries about technological competition. Even after the shock of the launching of the Soviet Sputnik, the United States did not feel the current pressure of technological advancements being made by potential adversaries, friendly competitors and even Third World countries. The introduction of Yugoslavian and Korean automobiles into the US market is just one more example of probable future events.

Recognizing this challenge, it is incumbent on the United States to use its technological resources much more aggressively. The President's former Science Advisor, Dr. Keyworth, recently said, "Technology and talent are virtually our only clear competitive advantages in a world where the dollar may be permanently overvalued, where foreign governments are subsidizing capital costs, and where foreign labor is often an order of magnitude cheaper than domestic labor."[2] However, the United States no

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1. NSF National Patterns of Science and Technology Resources, 1986.
2. Technology Review, Feb/March 1985, p. 45.

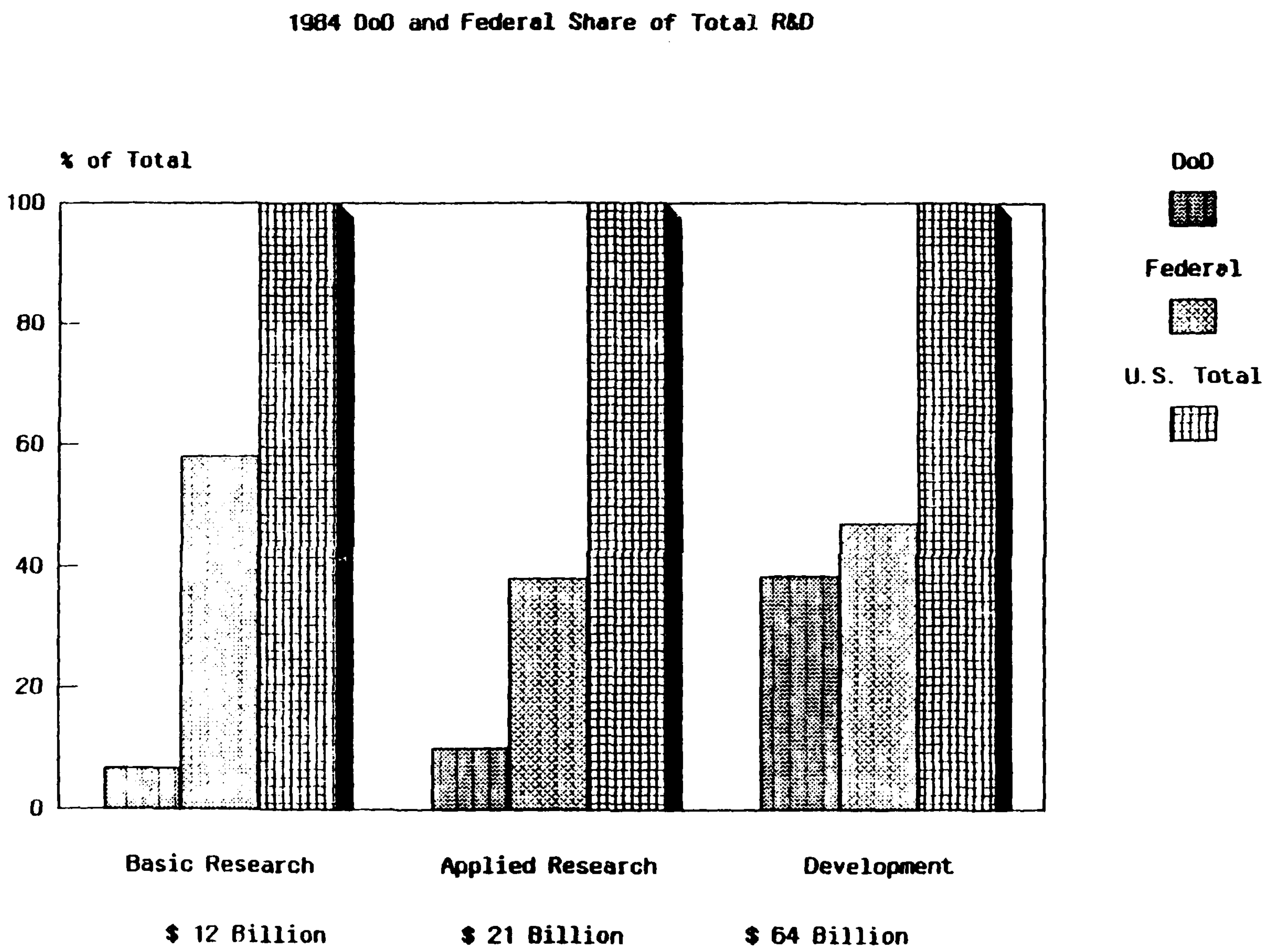
1984 DoD and Federal Share of Total R&D
% of Total
100
80
60
40
20
0
DoD
Federal
U.S. Total
Basic Research
Applied Research
Development
$ 12 Billion
$ 21 Billion
$ 64 Billion

FIGURE II-1

longer has the dominant share in talent, as other countries are investing in producing a large number of scientists and engineers who become involved in research and development. As Figure II-2 shows, in 1968 the United States was singularly ahead in scientists and engineers engaged in R&D per 10,000 labor force; by 1983, the Soviet Union was far ahead, and Japan and West Germany were close behind.

Compounding this problem is the challenge from the Soviet Union. The Soviets did not stop with Sputnik, but in effect had only started their large investment in technology for military purposes. As can be seen in Figure II-3, the Soviet Union has been investing in R&D, most of which is military, at a rate close to twice that of the United States. In the 1985 statement to Congress, the Under Secretary of Defense for Research and Engineering (USDRE) stated, "For more than two decades, the Soviet Union has maintained a massive national level program for acquiring critical military-related Western technology."[3] This well-executed program involving both legal and illegal means, is intensive and is both augmenting Soviet R&D efforts and shortening the time for Soviet weapons systems development. Subsequently, the Secretary of Defense listed some of the Soviet capabilities that have benefited from the acquisition of Western technology as being found in strategic warfare, tactical warfare, C^3I, and defense-wide support.[4] It is clear that the Soviets employ a top-down centralized approach in these efforts to obtain Western technology, to attempt to meet pre-determined technology requirements. This trend has been markedly accelerated by Secretary General Gorbachev as he "shakes up" the Soviet S&T establishment.

Technological competition comes not only from our adversaries, but from our Allies as well. Recently, Western Europe has been forging ahead in select areas of science and engineering having both a commercial and military utility. The data in Figure II-3 show that Western Europe and Japan have reached parity in their support of R&D as a national percent of GNP. This is in sharp contrast to 1968 when the United States was clearly ahead in its funding of R&D as a fraction of GNP. In addition to the superior work in high energy physics, Western Europe is cooperating on a number of technology thrusts:

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3. The FY86 DoD Program for Research, Development and Acquisition, March 7, 1985.

4. Soviet Acquisition of Militarily Significant Western Technology: An Update, September 1985.

Scientists & Engineers in R&D

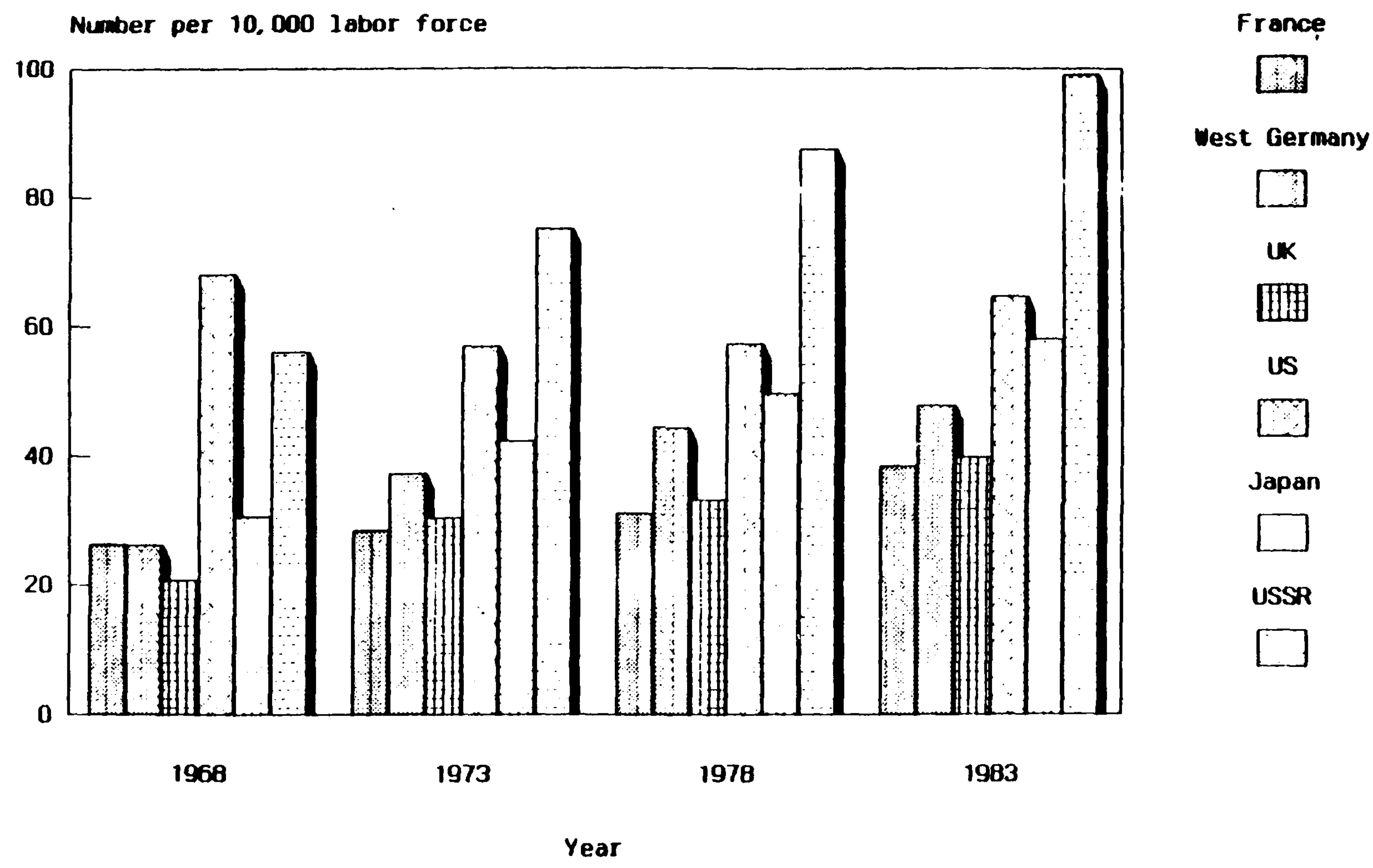

FIGURE II-2

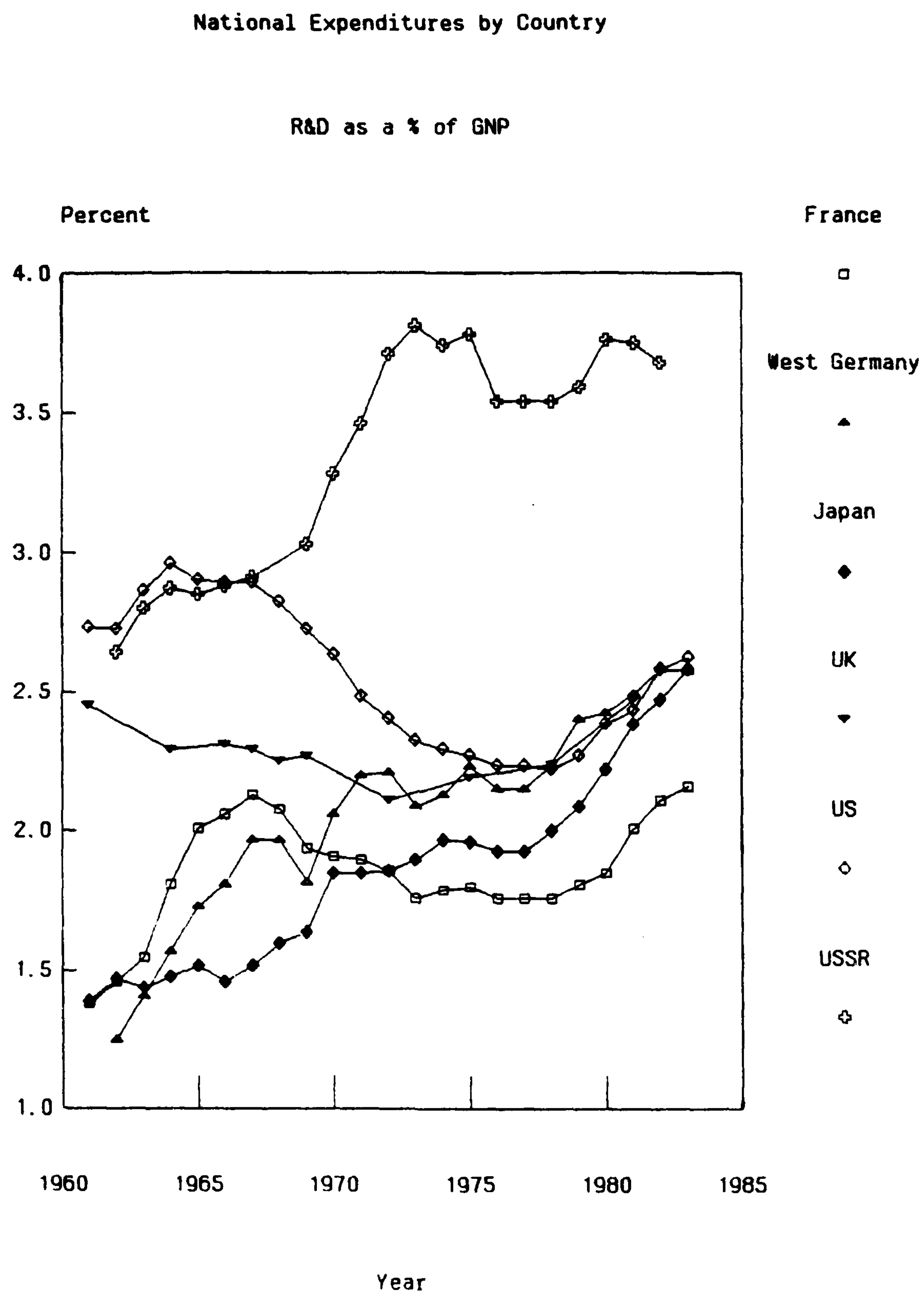
National Expenditures by Country
R&D as a % of GNP
Percent
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1960
1965
1970
1975
1980
1985
Year
France
West Germany
Japan
UK
US
USSR

FIGURE II-3

- Space (ESA);
- High Energy Physics (CERN);
- Molecular Biology (EMBO);
- Nuclear Fusion Energy (CEC);
- Nuclear Radioactive Waste (CEC);
- Information Technology (CEC); and
- Aeronautics (multiple sponsors).

In addition, when President Reagan launched the SDI initiative, Western Europe decided to launch the Eureka initiative to ensure itself that it would not fall behind in generic technologies that would spin off from SDI. Ten projects were identified and lead responsibility was given to certain countries. These were:

- Production of a standard microcomputer for education and domestic use (UK, France and Italy);
- Production of a new type of computer chip made of amorphous, or uncrystallized silicon (France and West Germany);
- Development of a high-speed computer (France and Norway);
- Development of a laser for cutting cloth in the apparel industry (France and Portugal);
- Development of membranes for water filtration to desalinate sea water (Denmark and France);
- Development of high-power laser systems (West Germany, France, Italy and the UK);
- Development of a system to trace pollutants (West Germany, Austria, Finland, the Netherlands and Norway);
- Development of a European research computer vehicle (Almost all Western European countries are interested in this thrust);
- Development of a diagnostic kit for sexually transmitted diseases (Spain and the UK); and
- Development of advanced optic electronics (France and Italy).

To fully utilize the results from the above efforts, West European countries are pledged to promote common standards and to promote increased cooperation.

Similarly, by focusing its resources in a number of key technologies, most of which also have defense applications, Japan has established itself as a front-runner in a wide variety of technology-based markets. By joining forces and forging a unified front of government and industry, Japan has developed a top-down, centralized and sophisticated industrial policy that balances competition and cooperation, yielding a steady stream of commercially successful innovation. These innovations have been targeted so far toward commercial uses, but it is also clear that many if not most have military applicability, and areas like electronics and advanced materials are key to a superior defense posture. This becomes quite evident when one looks at the results of Japan's own study in assessing their strengths and weaknesses in a number of areas, and their assessment of US and European positions (see Table II.1). Though the survey was performed in 1982, it clearly identifies a number of defense technologies in which the Japanese perceive themselves as being ahead of the United States. Their use of this type of data is for the purpose of national planning and targeting. Thus, the possibility that the Soviets could quickly capitalize on available Japanese technology for military purposes should be a significant US concern.

It is evident that the United States cannot continue to simply wait for technologies to independently appear and mature, in the face of the Soviet, Western European and Japanese centralized approaches described above. The Emerging Technologies Program described at Section II.D is intended to help meet this serious technology challenge.

B. PROBLEM

In summary, while the United States remains still the largest R&D performer in absolute terms, other countries are rapidly growing. The Soviet Union and Japan lead the United States in engineering degrees, the US surplus in trade in high technology has diminished, and the United States dominates in fewer high technology industries, many of which have defense applications. The fallout from the trade war with Japan in electronic integrated chip technologies is still being played out; some experts gave Japan the lead in the world in marketing the 1-megabit (1000K) chip as early as 1985.[5] In Figure II-4 we show the trend of Japanese exports, most of which are sold to the United States. The high technology exports are in electronic materials and other dual use products. Many of

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5. Science, Vol. 230, p. 918.

Table II.1

RELATIVE STRENGTH IN ADVANCED TECHNOLOGIES AS PERCEIVED BY JAPANESE IN 1982 NIKKEI SURVEY

	JAPAN	USA	EUROPE
I. COMPUTERS			
A. Fifth generation computers	A*	B*	B
B. Super computers	A	A	C*
C. Large computers	A	A	C
D. Mini computers	B	A	C
E. Personal computers	A	A	C
F. Software	C	A	A
II. SEMICONDUCTORS			
A. VLSI	A	B	C
B. Microprocessor	B	A	C
C. Manufacturing & test facility	B	A	C
D. Advanced devices	A	A	C
III. OPTICAL COMMUNICATION			
A. Fiber optics	A	B	C
B. L.D. communication system	B	A	C
C. Semi-conductor laser	A	A	C
D. Digital electron exchange	B	B	A
IV. FACTORY AUTOMATION			
A. Industrial robots	A	A	C
B. Numerical control machinery	A	B	C
C. Transport automation	B	A	B
D. CAD/CAM	B	A	B
E. Metal forming	A	B	B

* KEY: A = Leading
B = Following "A"
C = Trailing "A" & "B"

Table II.1 (continued)

	JAPAN	USA	EUROPE
V. NEW METALLIC MATERIAL			
A. Amorphous metal	B	A	C
B. Hydrogen storage alloys	B	A	C
C. Mechanical memory alloys	B	A	C
D. Super conducting material	B	A	C
VI. NEW CHEMISTRY-RELATED MATERIALS			
A. Fine ceramics	B	A	B
B. Engineering plastics	C	A	B
C. Carbon fibers	A	B	C
D. High performance osmosis membrane	B	A	C
VII. BIOTECHNOLOGY			
A. Interferon	B	A	B
B. Monochlonal antibodies	B	A	B
C. Bioreactor	C	A	B
D. New plants	B	A	B
VIII. NEW ENERGY SOURCES			
A. Amorphous solar battery	A	B	C
B. Nuclear fuel cycle	C	A	B
C. Coal liquefaction, gasification	C	A	B
D. Use of oil shale and oil sands	B	A	C
E. Decomposition of heavy crude oil	C	A	B
IX. AEROSPACE & DEFENSE			
A. Aircraft	C	A	B
B. Jet engines	C	A	B
C. Satellites and rockets	C	A	B
D. Missiles	B	A	C
E. Ships	B	A	C
F. Tanks	C	A	B

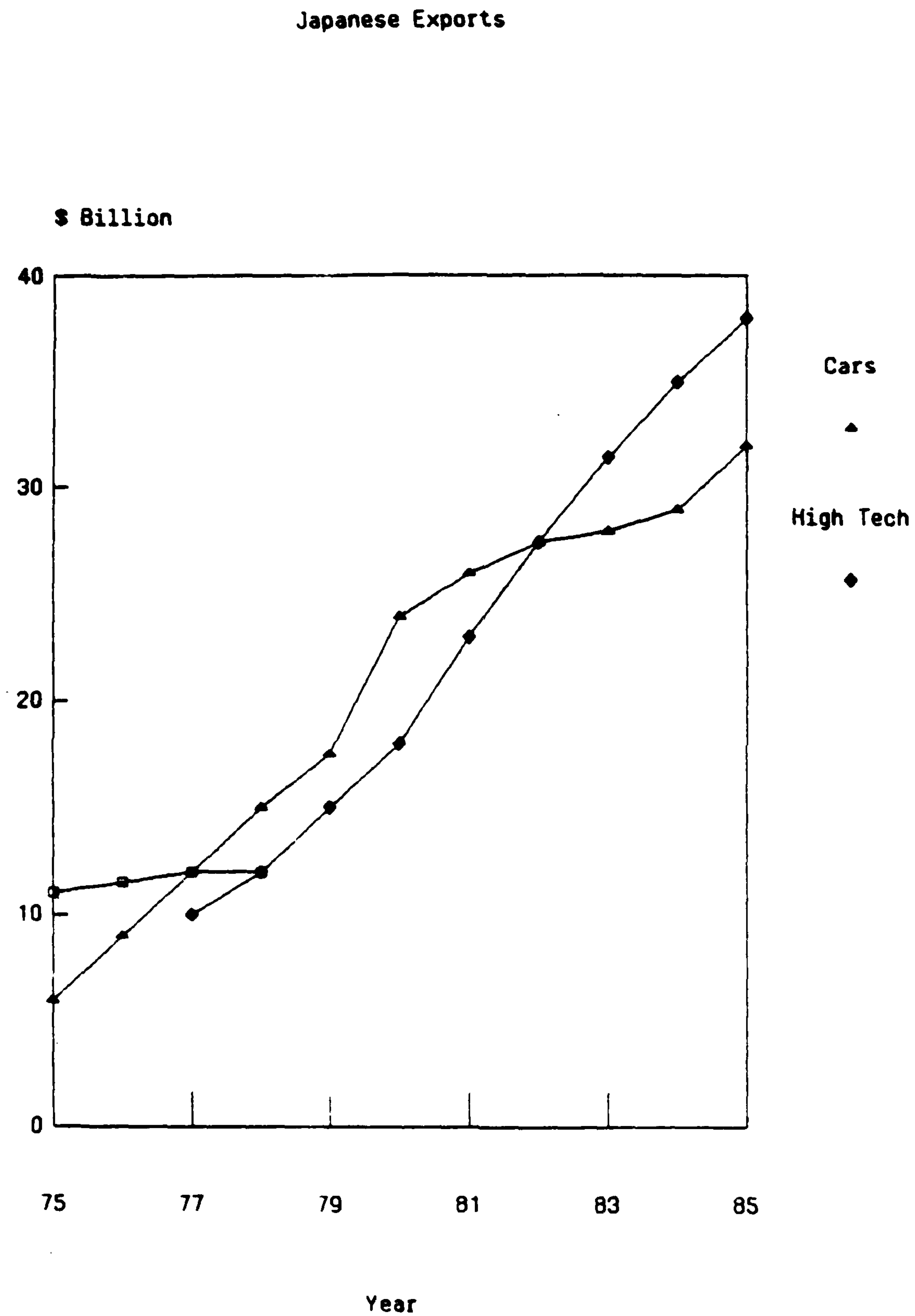
Japanese Exports
$ Billion
40
30
20
10
0
75
77
79
81
83
85
Year
Cars
High Tech

FIGURE II-4

the items are high quality, low cost state of the art devices easily adapted to DoD weapon system needs.

This narrowing of the technological gap between the United States and the rest of the world will continue. Consequently, to stay ahead, the United States must take measures to ensure that new technologies, most often still developed first here in the United States through its large investment in basic research, are also applied first in the United States. Complicating this matter of being first in applying research is the fact that, in many important areas of technology, there has been a shrinkage of time between basic research and application; the traditional time span of 10, 20 or even 30 years has shrunk in some areas to three to five years--therefore technology transition decisions must be made much more quickly. In areas like computer software, biotechnology, artificial intelligence, materials processing, and the like, research is literally taken from basic research laboratories and applied to commercial or defense systems within months.

A second aspect of this technology challenge is US dependence upon the programmatic means by which research initiatives and budgets are decided in the DoD and other Federal agencies. Differences persist between constituencies responsible for near-term programs versus those favoring the pursuit of longer-term and higher-risk technology opportunities. These difficulties have received criticism from the DSB and others in the past. Therefore, a continuing OSD/USDRE assessment process similar to the one described in this report appears necessary, both to address the interests of proponents of near- and longer-term research investment opportunities, and, to provide a "bridge" between these constituencies.

C. SOLUTION

From the Defense point of view, if technology leadership is our key resource, then a partial solution to this problem is our ability to identify and stay abreast of the progress in a number of key technologies that have been identified as critical to national security. Then, as quickly as possible, rapidly advancing and emerging technologies of potential importance must be followed on a continuing basis so that timely investments can be made to bring such technologies to a successful application phase. Concurrent with this approach, appropriate policy decisions must be made to ensure that the United States gets full benefit from such technologies, and to delay as long as possible their employment by our potential adversaries.

To accomplish the above, a large coordinated effort is required involving a sufficiently large group of technology experts so as to be able--on a continuous basis--to assess the increasing number of rapidly advancing and emerging technologies of potential importance to DoD. Such an effort should: (1) address the large number of rapidly advancing research areas; (2) provide a continuous monitoring of the foreign technological state of the art; (3) offer detailed current assessments of those areas deemed high priority; and, (4) integrate the above information in a succinct yearly update giving relative positions of the United States and the rest of the world, and progress made in getting the identified emerging technology closer to the application stage.

This report is the first of a planned series of such periodic reports, addressing the critical question of identifying and then tracking progress on a select number of defense related emerging and rapidly advancing technologies. It will synthesize information from a number of in-depth studies of individual technologies performed under this contract, as well as separate studies performed by SAIC for several other Government Sponsors.

In particular, SAIC operates three separate programs for the Government--the Foreign Applied Sciences Assessment Center (FASAC), the Japanese Technology Evaluation Program (JTECH), and the newly-begun Global Technology Evaluation Center (GTEC)--all of which have developed data of particular relevance to the ET Program.

D. OVERVIEW OF THE EMERGING TECHNOLOGIES PROGRAM

The purpose of the Emerging Technologies Program is to help the DoD to be on top of new technologies in order to shorten the time between research "ideas" and defense system applications, and to avoid technological surprises.

Technology forecasting is not a perfect science, nor will it become such in the near future but, by a diligent, thorough and continuous monitoring of the progress of specific areas of basic and applied research and carefully nurturing their development, one can predict fairly accurately their applicability and the time frame of development. Lasers, for example, from the time of their discovery, clearly had a military potential, although it was not clear in the beginning how they would be used. However, within a decade they were utilized in operational weapon systems. An example of the rapid progress made by solid state lasers is shown in Figure II-5. Other areas have less clear military potential but, once identified, they also must be followed due to their uncertain but potentially revolutionary impact on current or future weapon systems.

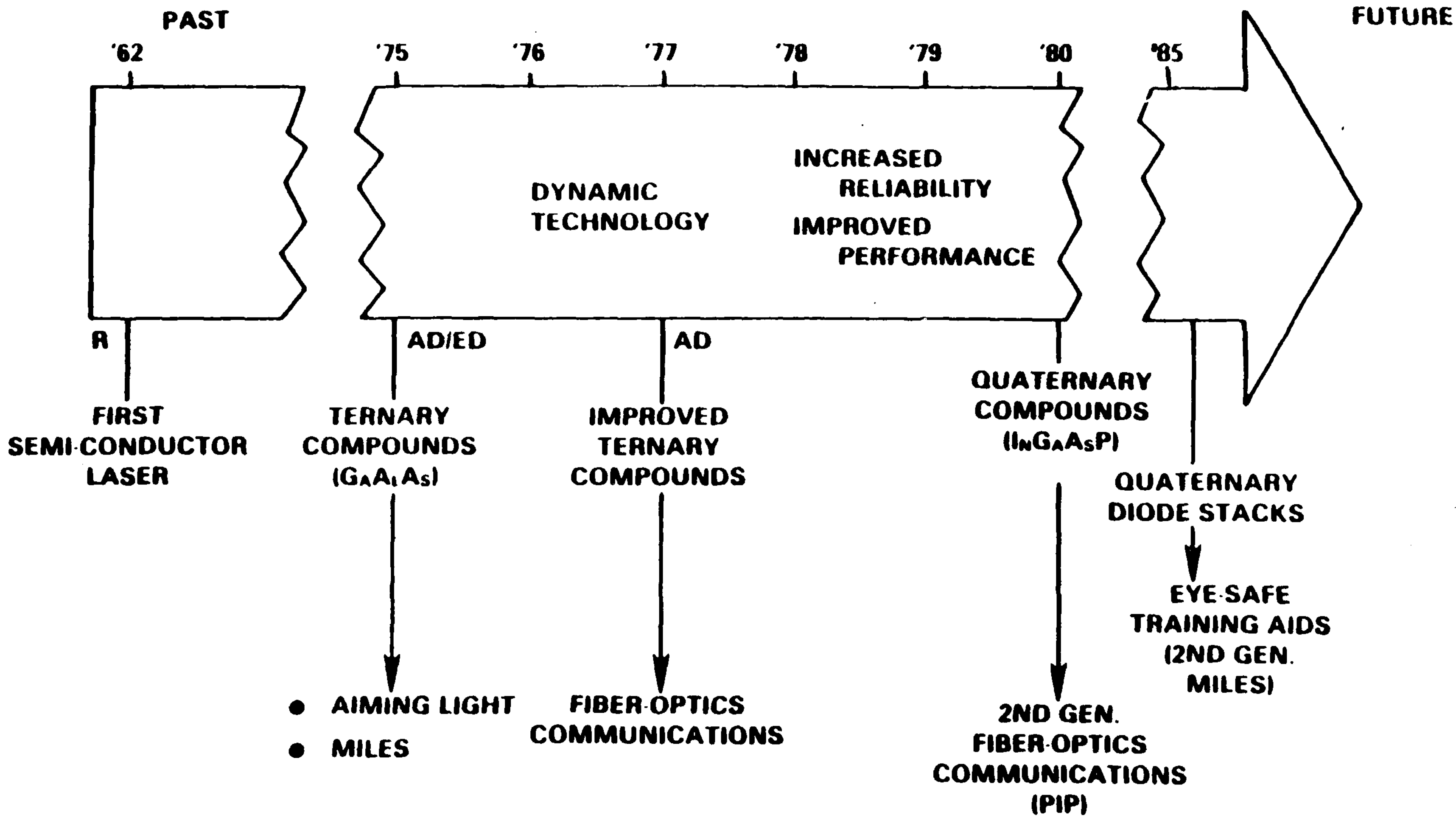

Figure II-5. **SEMI-CONDUCTOR LASER TECHNOLOGY DEVELOPMENT SYSTEM APPLICATIONS**

The approach that will be used in this report is to forecast emerging technologies utilizing proven methods:

- First, provide broad coverage (a quick sweep) of all areas of potential interest to the military and the commercial markets;
- This is followed by canvassing the DoD community for their current and future technological needs;
- Next, the above two processes are merged to form a select list of technologies judged to be potentially of high priority--this list is then assessed in considerable depth by panels composed of US experts; and
- Lastly, the in-depth reports are integrated, together with other studies performed by SAIC in assessing the state of technological progress in other countries, including the Soviet Union and Japan.

In summary, the SAIC Emerging Technologies (ET) Program covers four phases. They are:

- Phase I--A broad coverage study utilizing the Delphi process;
- Phase II--DoD application community prioritization workshops to identify Defense needs;
- Phase III--In-depth assessments of high priority areas; and
- Phase IV--Recurring update and Integration Report.

Phases I and II have been completed at the time of this writing, and Phase IV is represented by this report. Phases III and IV are "cyclic," with the first expert assessment panel (III-V Microelectronics) under Phase III concluded in early 1987. Figure II-6 displays all four phases of the ET Program.

It is the intent of this first Integration Report to integrate information obtained from Phases I and II of the ET Program and augment it with studies performed under other sponsorship, described in Volume II, Appendices 1 and 2.

Ultimately it is the objective of this program to generate a methodology for identifying key technology areas of high interest to the DoD and to apply this methodology to assist investment decisions affecting the science and technology programs (6.1, 6.2 and 6.3A). This effort is particularly timely since, with shrinking Federal budgets and major technological challenges from abroad, there currently exists no uniform process within the DoD that allows a continued updating of information which cuts across a wide spectrum of technologies.

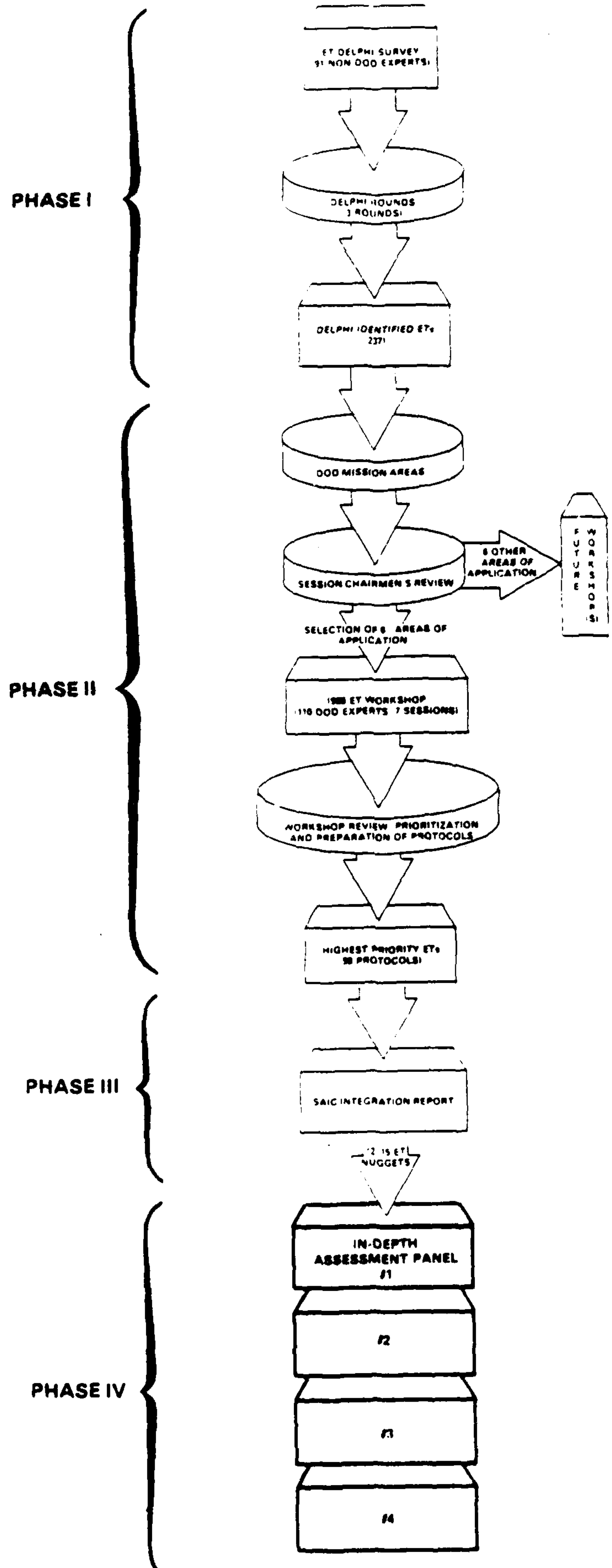

Figure II-6
"The Four Phases of the ET Program"

The approach adopted here has the following attributes:

- The Delphi process involves a wide segment of US R&D expertise and utilizes a proven technique to rapidly identify a large number of emerging technologies evolving from the US research programs. While this list might not be complete, when performed on a regular basis this method can be perfected to identify quickly a majority of the areas that are potentially important to the DoD.

- The Prioritization Workshop has two objectives. The first is to get the DoD application community to discuss the Delphi list and select those research areas deemed most important to them. The second is to elicit from the DoD application community research needs which can be factored in to develop a high priority list of areas worthy of further in-depth assessments. In effect, then, the Workshop distills the Delphi data--a major step toward identifying the few technologies of potentially highest value.

- The in-depth assessments stress those areas identified in the above process and provide the DoD with the most current picture of the state of the art of those technologies, here in the United States and in the rest of the world, and provide an up-to-date picture of funding levels, Sponsors and milestones needed to fully utilize the research results in new weapon system concepts.

- The Recurring Update and Integration Report (this being the first) puts all of these studies together and provides the DoD a clear snapshot of the current state of the selected high priority areas and other relevant data.

CHAPTER III
1985 DELPHI SURVEY

A. INTRODUCTION

The importance of obtaining non-DoD inputs to the identification of emerging technologies is clear. As discussed in Chapter II, the DoD is actually a minority investor in exploratory research, and it is thus difficult for DoD research managers to develop a good understanding of the technologies viewed as most promising by the private sector. It was decided to use the Delphi technique to provide these inputs, with a group of approximately 100 experts, primarily from universities and industry, as respondents.

The Delphi technique was originated by Olaf Helmer and Norman Dalkey at the Rand Corporation in 1953, and is intended to make the best use of a group of experts to obtain answers to questions involving their informed intuitive opinions. The method involves a series of questionnaires including controlled feedback of the results of previous questionnaires in the series. In this feedback, there is no direct confrontation of one expert by another, and an attempt is made not to associate opinions with specific individuals. These steps are taken to avoid the multitude of extraneous psychological factors involved in decisions by committee meetings. The technique has been used for a wide variety of technological forecasts. A fuller description of the method and discussion of some of the forecasts can be found in the book by Helmer.[1]

The Delphi procedure provides many important ingredients for this forecast of emerging technologies. Most relevant is the possibility of injecting "wild" ideas anonymously, though subject to the criticism of the group. This inevitably means that some of the suggestions are, in fact, overly optimistic--but the indications of this are to be provided by the opinions of other respondents. By using this format, we have tried to obtain suggestions for emerging technologies unfettered by bureaucratic impediments, either government or private.

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1. Olaf Helmer Looking Forward--A Guide to Future Research, Sage Publications, 1983.

The Delphi has often been used to reach a "consensus," for example, to provide a majority view of when a given development will occur by quoting an interquartile range of dates to the group in the penultimate round, and thus suggesting that the respondents outside the range should "correct" their view for the final round, or justify their disagreement with the majority. Nevertheless, the Delphi provides the respondent the opportunity to persist in his dissent, without the peril of personal confrontation that he could expect in a conference environment. The important point for our application is that we have no desire to force a meaningless consensus here. It is true that outstandingly perspicuous ideas can be overwhelmed by negative peer review. However, since our desire is to explore the full range of possibilities, we have not eliminated items between rounds, and will report in this chapter, and in subsequent work, the complete range of responses received.

We have experienced a substantive problem in settling the compromises that must inevitably be made in the length and/or detail of the questionnaire if one is to expect responses from the very busy individuals chosen. Among the very practical suggestions made to us by Dr. Olaf Helmer was that we keep the questionnaire short enough that a respondent could answer it in less than two hours. We have tried to adhere to this rule, but even so we have found that the physical bulk of the third round questionnaire resulted in both delays and dropouts. On the other hand, some observers have complained about the "lack of detail" in the descriptions of the individual technologies in the Delphi, leading in some cases to ambiguity.

In the following sections, we first discuss the choice of the participants, and then discuss the questionnaire development, processing, and results of each round.

B. THE PARTICIPANTS

Participants in the Delphi Survey were chosen for their known active involvement in research and technology development. In order to fulfill the objective of identifying the broadest range of potential technologies, the majority of participants were selected from academia and industry. These people are, in general, outstanding researchers or directors of research who have also had prior exposure to the technical problems of the DoD. This group was augmented by a smaller number of key research directors in government. An attempt was also made to assure coverage in all identifiable areas in science and engineering, with a weighting toward those areas in which the most rapid developments are occurring.

Table III.1 lists all respondents who have participated in one or more Delphi rounds, except three respondents who asked that their names not be listed in this report. Those designated with a "T" are those who participated in the first, trial round.

C. FIRST ROUND

The first Delphi round was designed to produce an initial list of technologies, to serve both as candidates for consideration by a larger group and also as exemplars of the desired responses in the second and following rounds. Twenty-four individuals participated in this "test" round. The complete questionnaires for each round appear in Appendices 3, 4, and 5, respectively.

Throughout the Delphi process, the questions have been designed with the objective of helping to focus attention on specific "technologies" that the respondents felt were emerging or about to emerge (see second paragraph of introduction to first Delphi questionnaire).

Though it is relatively simple for all of us to understand what "technology" means, common usage gives us little feeling for what level of aggregation comprises "a technology." Thus, commonly, one may speak loosely of "ICBM technology" but this can be decomposed into "guidance technology," "warhead technology," "propulsion technology," etc., while each of these can be decomposed into more detailed specifics, and some of those subdivided further. The approach that we have tried to use is to conform, insofar as possible, to the level of aggregation used by OSD (e.g., in the USDRE posture statement) in defining a "technology area," and then to solicit, in the Delphi, "technologies" of a more specific nature that could be grouped within these, or similar technology areas. In the first Delphi round, the first question addressed general technology areas (see questionnaire). Though there were some thoughtful responses to the question, it became apparent that most were too general to communicate an appreciation of the connection between possible advances in the technology area and emergence of opportunities for specific applications.

The second question in the first questionnaire was much more useful in eliciting specific responses. The question asked for the description of a technology that "could be made to emerge from the concept stage" within the next 15 years, plus potential applications, plus "Why do you think it is possible?". The technology descriptions were used essentially verbatim as inputs to the second Delphi round. Some results were rejected by

Table III.1
DELPHI SURVEY RESPONDENTS

1. ALBUS, Dr. James S. (T)
2. ATLAS, Dr. David (T)
3. BALDESCHWIELER, Dr. John (T)
4. BANKS, Dr. H. Thomas
5. BARSCHALL, Dr. H. H.
6. BATES, Dr. John B.
7. BAUGHMAN, Dr. Raymond
8. BEDARD, Dr. Fernand
9. BEMENT, Jr., Dr. Arden L. (T)
10. BENNETT, M.D., Dr. Ivan (T)
11. BRINKMAN, Dr. William F.
12. BRODSKY, Dr. Marc H.
13. BROWN, Dr. William M. (T)
14. BYER, Dr. Robert L. (T)
15. CARLSON, Jr., Dr. Herbert C.
16. CAULFIELD, Dr. John H.
17. CHURCHILL, Dr. Stuart W.
18. CLIFFORD, Dr. Steven F.
19. COFFEY, Dr. Timothy (T)
20. COOPER, Dr. Leon N
21. CURRAN, Dr. Edward T.
22. DAVIS, Dr. Steven J.
23. DEAN, Dr. Anthony M.
24. FAETH, Dr. Gerald
25. FETTERMAN, Dr. Harold
26. FRANKEN, Dr. Peter A. (T)
27. GEBALLE, Dr. Theodore H.
28. GEBHARDT, Dr. Joseph J.
29. GLASSMAN, Dr. Irvin (T)
30. GLIMM, Dr. James
31. GREGG, Dr. Michael C. (T)
32. HADDAD, Dr. Genevieve M.
33. HAMMOND, Dr. George S.
34. HAPPER, Jr., Prof. William
35. HEICHE, Dr. Gerhard F. A.
36. HOSLER, Dr. Charles L.
37. INFANTE, Dr. Ettore F.
38. KAHAN, Dr. William M.
39. KAILATH, Dr. Thomas (T)
40. KAPLAN, Dr. Richard E.
41. KATZ, Dr. Robert N.
42. KNAPP, Dr. Edward A. (T)
43. KRISTIANSEN, Dr. Magne
44. KROGER, Dr. Harry
45. KRUGER, Dr. Jerome E.
46. KUO, Dr. Kenneth K.
47. LANZEROTTI, Dr. Louis J.
48. LAUER, Dr. James L.
49. LEWIS, Dr. Clark H. (T)
50. LILLY, Dr. Douglas K.
51. LUDEMA, Dr. Kenneth C.
52. MILLER, Dr. G. L.
53. MOORE-EDE, Dr. Martin C.
54. MUNSON, Mr. John
55. NARATH, Dr. Al
56. NASTROM, Dr. Gregory D. (T)
57. NOWLIN, Jr., Dr. Worth D.
58. PATEL, Dr. Chandra Kumar
59. PENZIAS, Dr. Arno A. (T)
60. PEW, Dr. Richard W.
61. REDDY, Dr. Raj (T)
62. REDIKER, Dr. Robert H.
63. RHEINBOLDT, Dr. Werner C.
64. RICE, Dr. John R.
65. ROBERTS, Dr. Fred S.
66. SCARF, Dr. Frederick L.
67. SCHAFER, Dr. Ronald W.
68. SCHAPERY, Dr. Richard A.
69. SCHMITT, Dr. Roman A.
70. SCHOLTZ, Dr. Robert A.
71. SCULLY, Dr. Marlan O.
72. SEERY, Dr. Daniel J.
73. SENIOR, Dr. Thomas B. A. (T)
74. SMITH, Dr. James A.
75. SPICER, Dr. William E. (T)
76. SPINDEL, Dr. Robert C.
77. STEINBERG, Dr. M. A.
78. TOWNES, Prof. Charles
79. TRICOLES, Dr. Gus P.
80. TSUI, Dr. Dan
81. ULMER, Dr. Kevin M. (T)
82. WALKER, Dr. Raymond F. (T)
83. WEEKS, Dr. Wilford
84. WEINTRAUB, Dr. Daniel J. (T)
85. WINGARD, Jr., Dr. Lemuel
86. WOODALL, Dr. Jerry M.
87. YARIV, Dr. Amnon
88. ZIMET, Dr. Eli

89-91. "Anonymous Respondents"

Key: (T) = participant in first, trial Delphi round the SAIC staff as not being a "technology" (a typical example is a proposal to set up a group to try to crack US cipher systems "from the outside" by unspecified means--an organizational proposal of possible merit). The type and level of detail provided by the respondents in response to "Why do you think it is possible?" was highly variable, however. In the example given in the questionnaire, the answer to "why" was given in terms of possible physical alternatives. Though a substantial fraction of the responses were of the same type, many were quite laconic (e.g., the statement "by extrapolation").

D. SECOND ROUND

In the design of the second round, the basic input from round one was a list of 65 "candidate technologies." The respondents were asked to vote on the availability of the technology (in five-year increments) and on its value (on a five-point scale). Dr. Helmer suggested that we attempt to split the technologies into categories, so that respondents would be able to skip categories that were outside their expertise. The categories were developed by examination of the list of "candidate technologies," and therefore cannot be expected to span all possible areas. Because of this fact, plus the uneven sizes of the areas, no attempt was made to force the participants to respond only in a specific number of areas. This may have led to considerable voting by non-experts in some categories. It can be argued that one need not be an expert in a particular area to appreciate the importance of a development, even though it might be difficult to predict when the development might occur. It thus turned out that, for each technology, a few respondents estimated the importance, but gave no availability date. The general nature of the responses is illustrated in Table III.2. It is not surprising that the respondents appeared to value most candidate technologies as above average. For example, the mean "value" for the ten items in Table III.2 is 2.75 and the median is 3 (where 2 is defined as "average"). It is also evident that there was a wide spread in the estimated dates of availability, possibly due in part to individual differences in interpretation of the meaning of "availability" or the definition of the technology. The instructions stated that "availability" presumes a successful demonstration of the technology; nevertheless, there was usually a small minority stating that a given technology was available in 1985. The ambiguity in definition of individual technologies varies substantially from one item to the next. A more complete discussion of the voting results from round two is incorporated into the discussion of round three (below).

TABLE III. 2 SAMPLE SECOND ROUND DELPHI SURVEY RESULTS

OPTICS AND LASERS	VALUE					AVAILABILITY							
	0	1	2	3	4	1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-never	Prefer not to answer	no dates
1. Ultra low-loss fiber optics	1	2	8	22	22	6	32	8	6	1	1	20	1
2. Sub-wavelength optical imaging by gradient techniques	1	2	8	9	4	1	11	8	3	1		51	
3. Optical fiber sensors for measurement of physical parameters	1	2	16	33	8	11	32	7	5	2		15	3
4. Optical fiber sensors for measurement of chemical properties	1	5	21	19	7	4	26	11	4	1	1	22	6
5. Real-time holographic interferometry through fiber optics	1	4	14	14	6	2	13	12	7		3	36	2
6. Coherent gamma-ray sources (e.g., X-ray lasers)		5	8	16	18	1	12	7	15	6	3	28	3
7. Steerable laser diode arrays at powers of approximately 1 kw/cm^2		1	3	22	11		12	6	12	6		38	1
8. Rare-gas halide excimer lasers with high efficiency and high energy output		2	7	23	6	1	16	10	7	4		37	
9. Nd: YAG lasers with average 1 kw, for manufacturing		2	23	14	3	1	24	9	5	2		33	1
10. Co_2 lasers for manufacturing with power 10 kw		2	22	14	6	6	25	7	3	1		31	2

The participants were also asked to suggest additional candidate emerging technologies comparable to those on the questionnaire. In retrospect, it is unfortunate that they were allowed to submit only the technologies, without the back-up structure of the second question of the first round. Because these technologies were "one liners," many of the participants in the Workshop (see Chapter IV) interpreted them as "needs statements," since no backup rationale was available. The questionnaire did not ask for "needs statements," and it thus must be assumed that the respondents honestly believe that their suggestions are possible and reasonable. The validity of these suggestions was subject to peer review in the third round, but only a portion of the third round was completed prior to the Workshop.

The SAIC staff chose from the responses to the second questionnaire an additional 172 candidate emerging technologies to be added to the 65 candidates from round one, so that there was a total of 237 candidates to be considered in the next round.

E. THIRD ROUND

Because of the large number of candidate technologies resulting in the second round, it became all too obvious that respondents would need a simple mechanism for choosing only a small portion of the third round questionnaire--that portion in which they judged themselves to be most competent. To make this possible, the technologies were divided into twelve categories, each intended to be homogeneous and a likely "area of expertise." Fortunately, it also turned out that there were about 20 items in each category, as shown in Table III.3. The questions in each category were stapled together with a cover sheet giving the collated responses from round two for the relevant questions on that category. In the distributed questionnaire, the cover sheets were of different colors, to accent the separability.

The instructions for the questionnaire (see Appendix 5) requested the respondents to pick the three or four categories in which they felt most expert and to answer only in those. The respondents were again asked for availability dates and judgments of the value of each technology: (a) specific milestones/research developments required to realize the technology (as a guide to estimating availability dates); and (b) specific applications (as a guide to "value").

Table III.3
THIRD ROUND DELPHI TECHNOLOGIES

	TECHNOLOGY CATEGORY	NUMBER OF TECHNOLOGIES
A.	BIOTECHNOLOGY, MEDICINE AND LIFE SCIENCES	23
B.	CHEMISTRY AND CATALYSIS	12
C.	COMBUSTION, PROPULSION AND ENERGY	19
D.	COMMUNICATIONS, RADAR AND SIGNAL PROCESSING	20
E.	COMPUTERS	18
F.	DIRECTED ENERGY RELATED TECHNOLOGY	20
G.	ELECTRONIC MATERIALS AND DEVICES	25
H.	FLUID DYNAMICS	15
I.	MACROSCOPIC MATERIALS	25
J.	OPTICS AND LASERS	13
K.	REMOTE SENSING, OCEANOGRAPHY AND METEOROLOGY	25
L.	ROBOTICS, AUTOMATION AND MACHINE INTELLIGENCE	22

There were 65 responses, and on the average, each respondent answered in three technology categories, though some answered in fewer categories (e.g., six respondents answered in only one category), and some answered in more (four respondents answered questions in six or more categories). Because of the freedom of choice, the number of self-declared experts varied among categories, from a low of 10 for biotechnology and life sciences to a high of 24 for computers, as shown in Table III.4. Since respondents did not always address every technology within a category, the number of responses was very small for some technologies.

The technical substance of the responses is discussed below.

F. IDENTIFICATION OF SOME IMPORTANT PROJECTED TECHNICAL ADVANCES

The responses from the first three Delphi rounds can be assembled in a composite worksheet for each technology, as illustrated in Figure III-1. In this worksheet, the two figures at the top show the responses to the questions concerning date of availability (left side) and value (right side). The solid lines correspond to Round 2, and the dashed lines with scales in parentheses to Round 3 results.

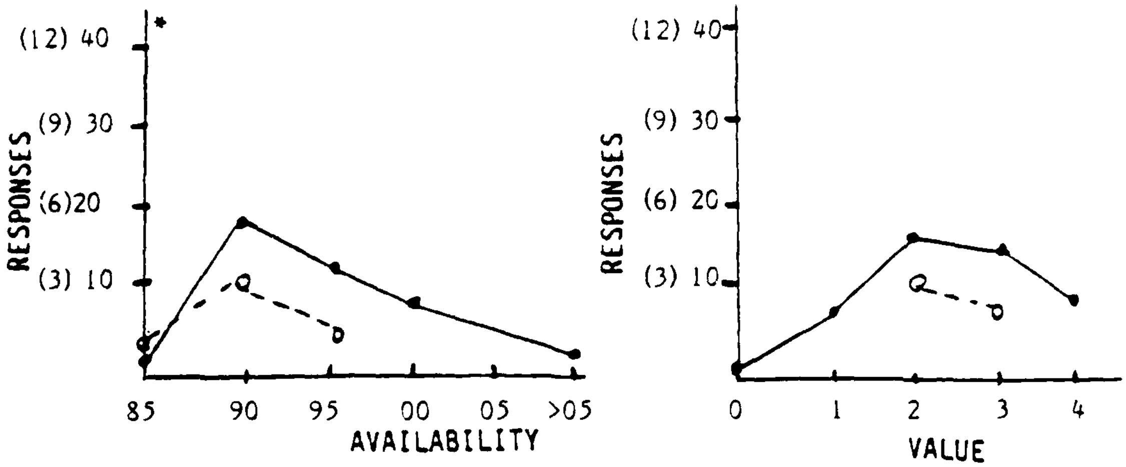
The remainder of the page lists the combined "needed developments" and "applications" listed by respondents to Round 3. These listings are essentially verbatim compilations of the several respondents' contributions and thus may be overlapping and inconsistent. Preliminary versions of these data sheets were first developed for use at the Annapolis Workshop (with the responses available at that time). The example in Figure III-1 shows the smaller number of responses for a given technology in Round 3, and an associated "sharpening up" of the estimates of availability and value.

Table III.4

NUMBERS OF EXPERT RESPONDENTS FOR EACH CATEGORY
THIRD ROUND DELPHI TECHNOLOGIES

	TECHNOLOGY CATEGORY	RESPONDENTS
A.	BIOTECHNOLOGY, MEDICINE AND LIFE SCIENCES	10
B.	CHEMISTRY AND CATALYSIS	14
C.	COMBUSTION, PROPULSION AND ENERGY	15
D.	COMMUNICATIONS, RADAR AND SIGNAL PROCESSING	13
E.	COMPUTERS	24
F.	DIRECTED ENERGY RELATED TECHNOLOGY	11
G.	ELECTRONIC MATERIALS AND DEVICES	23
H.	FLUID DYNAMICS	11
I.	MACROSCOPIC MATERIALS	17
J.	OPTICS AND LASERS	16
K.	REMOTE SENSING, OCEANOGRAPHY AND METEOROLOGY	16
L.	ROBOTICS, AUTOMATION AND MACHINE INTELLIGENCE	20

REAL-TIME HOLOGRAPHIC INTERFEROMETRY THROUGH FIBER OPTICS



NEEDED DEVELOPMENTS:

- Solution to the basic problem of image transmission in fibers.
- Coherent single mode fibers and fiber arrays.
- Fiber optic dividers, modulators.
- System development, especially sensor for long wavelengths and conversion of data to visible images.
- Innovative data processing that is rapid enough for "real-time" work.
- Demonstration in real working environments.

APPLICATIONS:

- Real time imaging with wavelengths long compared to visible light wavelengths.
- Vibration analysis of complicated structures; convenience of transport.
- Limited "internal" testing of apparatus.
- Robotics vision; quality control.
- Real time operational holography for diagnostics, without present size, handling and packaging constraints.
- Optional testing.

Figure III-1

Illustrative Composite Responses from
Delphi Rounds 2 and 3 for One Technology

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* The solid line refers to Round 2 and the "10's" scale; the dashed line refers to the Round 3 and the "3's" scale (in parentheses).

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CHAPTER IV
1985 EMERGING TECHNOLOGIES WORKSHOP

A. BACKGROUND

The preceding chapter describes the Delphi broad coverage of emerging technologies, culminating in a list of 237 candidate emerging technologies. In developing that list no specific defense requirement was used to prioritize the technologies. The purpose of this ET Workshop was to provide a forum wherein the DoD applications community could identify current and future "needs" and to select those technologies (out of the Delphi list) which could most closely satisfy these "needs." The first of several such Workshops was held in Annapolis, MD at the US Naval Academy on 17-19 June 1985. The meeting was unclassified and was attended by 128 DoD in-house technical experts, mostly from laboratories, and other selected invitees from Government organizations, such as NASA, DoE, OSTP, NSF and representatives from the Intelligence Community. A second companion Workshop dealing with Environmental Sciences was held at the Naval Research Laboratory in November 1985. The results of that Workshop are presented in Volume III of this Integration Report.

B. PREPARATION PROCESS

The DoD current and future needs are extremely diverse. In research and exploratory development, they are organized along technology areas. In fact, many technologies are important in a number of mission areas. For instance, using a previously cited example, low energy lasers, we see them used today in a variety of military field operations: laser surveillance; laser information transfer and communication; training aids; chemical/biological agent/exhaust detection; advanced laser sensors; data processing; holography; laser material preparation; and optical countermeasures; etc.

The approach chosen was first to identify and categorize DoD application areas. Some of these resemble mission areas, others are equipment or information needs. There was no "best" solution to this problem but several options were available. For purposes of this project we developed 13 application or requirement areas, listed at Table IV.1.

After some discussion with OSD, the military Services and other government agencies, six broad areas were selected for examination at this first ET Workshop. (It should be stressed that these six areas should not be viewed as more important to DoD

Table IV.1
INITIAL ET APPLICATION AREAS

- Command, Control and Communications
  - electronics
  - computers, hardware & software including AI
  - man/machine interface
- Strategic Defense Initiative
- Search and Surveillance
  - target acquisition
  - CM & CCM
- Mobility (Vehicles)
  - air/land/sea
  - avionics & fire control
  - man/machine interface
- Propulsion and Power
  - airbreathing
  - rocket
  - stored energy
- Materials
  - electronic
  - non-metallic structural
  - metallic structural
  - protective
  - biotechnology
- Electronic Warfare
  - ASW
  - radar
  - microwave
- Manufacturing
  - robotics
  - machine vision
  - integrated cells (factory of the future)
- Weapons (non-nuclear)
  - missiles
  - explosives
  - flames
  - CW
  - mines
  - insensitive explosives
- Training
  - training aids
  - man-machine interface
  - leadership
- Logistics and Procurement
  - reliability
  - effectiveness
  - interoperability
  - low cost with quality material
- Life/Medical Sciences
- Environment (air, ocean, land and space)

missions than the other seven. In fact several, like weapons, are clearly of critical importance to the mission of DoD. Rather, the six areas were chosen on the basis of current need of information and because of the logistics problem of being able to only hold about a maximum of six parallel sessions at one time. Therefore, the seven areas not addressed at the 1985 Workshop will be considered as candidates for future Workshops. The six broad areas were then refined to a specific list of topics and a final list of Workshop categories: C^3; Mobility; Search and Surveillance/Electronic Warfare; Directed Energy (as applied to SDI); Manufacturing; and Mission Support. At the request of the Sponsor, Mission Support was divided into two sessions, Human Factors and Biotechnology.

C. WORKSHOP STRATEGY

A nationally known engineer, well acquainted with DoD needs, was chosen as the overall chairman of the Workshop. Professor Karl F. Willenbrock, at the time of the Workshop, was the Cecil H. Green Professor of Engineering at Southern Methodist University and former dean of the School of Engineering and Applied Science. Prior to joining the SMU faculty, Dr. Willenbrock was Director of the Institute for Applied Technology at the National Bureau of Standards in Washington, DC. Before taking this position, he was Provost and Professor of the Faculty of Engineering and Applied Sciences at the State University of New York at Buffalo and Associate Dean of Engineering and Applied Physics at Harvard University. He is a Fellow and served as President of the IEEE in 1969. Currently, Dr. Willenbrock is Executive Director of the American Society for Engineering Education, a member of the US Activities Board and chairs the IEEE Committee on Technology Transfer. Dr. Willenbrock is also active in a number of other engineering and professional societies: a member of the National Academy of Engineering, currently completing a six-year term as a member of its governing Council; a member of the National Academies Committee on Science, Engineering and Public Policy; former member of the Council of the American Association for the Advancement of Science, serving as chairman of its Section on Engineering. Professor Willenbrock has also served on the Board of Directors of the American Society for Testing and Materials and currently chairs the Committee on Research and Technical Planning.

1. Session Chairmen Selection

For each application area, a session chairman was also chosen, selected on the basis of current knowledge of the specific areas in question.

The chairman for the Search and Surveillance session was Dr. Robert J. Lontz. Dr. Lontz is Director of the Physics Division at the Army Research Office. He is also responsible for the Army's Target Acquisition Technology Base Program and performs assessments of the user needs of the Army's Training and Doctrine Command. Between 1978 and 1980 he served as the Deputy Director for Research in ODUSD (R&AT).

The C^3 session chairman, Mr. Albert R. Lubarsky, is the Director of long range planning in the Office of the Assistant Secretary of Defense for C^3I. In that capacity he is responsible for integrating research across all C^3 areas. He also serves as chairman of the technology panel for C^3 of the Joint Directors of Service Laboratories, an activity of the Joint Logistics Command.

The Mobility session was chaired by Mr. Raymond Siewert. Mr. Siewert is the Director of the Engineering Technology Office in ODUSD (R&AT). In this capacity he is responsible for the Science and Technology programs (6.1, 6.2 and 6.3A) in materials, vehicles, aeronautics, and space technology. He also serves as co-chairman on the DoD/NASA Aeronautics and Astronautics Coordination Board.

The Manufacturing session was chaired by Dr. Vincent J. Russo, Acting Director, Manufacturing Technology Division, Air Force Wright Aeronautical Laboratories. Prior to this position, Dr. Russo held several management and technical positions within the Air Force Materials Laboratory including: Director of the Manufacturing Science Program, Director of the Metals and Ceramics Division, Assistant Chief of the Manufacturing Technology Division, Chief of the Metals Behavior Branch, Deputy Director of the Advanced Metallic Structure Advanced Development Program, and Project Engineer for Materials Support to the C-5A Program. As Acting Director of the Air Force's Manufacturing Technology Program, he is responsible for planning, organizing, and directing the activities of the Manufacturing Technology Division of the Air Force Wright Aeronautical Laboratory's Materials Laboratory.

The Directed Energy session was chaired by Dr. Matthew White, currently with the Office of Innovative Technology, Strategic Defense Initiative Office. Dr. White's pre-SDIO responsibilities included those of senior scientist at the Air Force Geophysics Laboratory, Hanscom Air Force Base, MA.

The Human Factors session was chaired by Dr. Joseph Zeidner, Research Professor of Public Policy and Behavioral Sciences, Graduate School of Arts and Sciences, at George Washington University. Before joining the University in the Fall of 1982, Dr. Zeidner was the Technical Director of the Army Research Institute and Chief Psychologist of the US Army. He spent more than 30 years in military behavioral sciences research. Recently, he co-authored Behavioral Science in the Army: A Corporate History of the Army Research Institute, to be published by the Government Printing Office, and edited a two-volume work, Human Productivity Enhancement, to be published by Praeger. Dr. Zeidner's current interests include person-computer interaction, human factors in systems design, cognitive science, personnel selection, and training technology.

The chairman of the Biotechnology session was Captain James Vorosmarti, Jr., MC, USN, the Assistant for Medical and Life Sciences R&D to the Under Secretary of Defense for Research and Engineering. He is responsible to the Secretary of Defense for oversight of and policy concerning all of DoD medical and life sciences R&D including non-medical biotechnology.

It is again noted that the selection of these seven session "Areas of Application" did not connote "higher priorities," but rather were those areas which the Sponsor decided to address at this 1985 ET Workshop.

2. Planning Meeting for ET Workshop and Session Chairmen

One month prior to the Workshop itself, the session chairmen/representatives met at SAIC/McLean with the Sponsor (DUSD/R&AT) and Sub-Sponsors (NASA and DoE) to be briefed on the ET Program status in general and the forthcoming Workshop and supporting Delphi data in particular. Each session chairman was requested to:

- "define and scope" his Area of Application;
- identify candidate session panelists; and

- pre-select Delphi ET responses relevant to his session Area of Application.

The agenda for this meeting is shown in Appendix 8.

3. Selection of Workshop Participants

In order to encourage the participation of DoD experts actively engaged in programs relevant to the Emerging Technologies session areas of application, SAIC briefed appropriate Service and agency officials in behalf of the Sponsor and requested the nomination of names of potential Workshop participants. The DUSD (R&AT) then formally invited the Services to nominate session members to represent their constituent interests. With few exceptions, this "bottom up" nomination process resulted in appropriate Workshop representation; however, there were several pertinent "lessons learned" in this regard, addressed in Chapter VI.

To a large degree the Workshop session participants were selected on the basis of their involvement in development programs (rather than research) and, in many cases, were for the first time asked to help identify research areas of direct interest to them. Table IV.2 provides a summary of OSD, agency, Service and subordinate organizations represented by the Workshop attendees.

D. ET WORKSHOP PROCEDURES

1. Agenda

The Workshop met in plenary session the morning of the first day. In addition to the agenda items listed in Appendix 9, the Delphi and data aggregation processes were described and discussed in detail, as were procedural instructions for the conduct of session tasks.

The sessions met separately the afternoon of the first day to review the technologies initially selected by the session chairmen at the Workshop Planning Meeting the month earlier. Internal session working procedures were developed, and initial "matches" made of session members to candidate ETs.

TABLE IV.2
1985 ET WORKSHOP REPRESENTATION-
109 SESSION MEMBERS

OSD (5)

ASD (C^3I)	-	1
SDIO	-	1
USDR&E	-	3

ARMY (20)

ARO	-	1	Army Tank Automotive Command	-	2
DAMA-ARR	-	1	HQ, USACE	-	1
AMMRC	-	1	HQ, USAMRDC	-	2
RDA	-	2	Army Research Institute	-	1
CEC	-	2	NVEOL	-	2
Harry Diamond Laboratories	-	1	Electronic Warfare Lab, Ft. Monmouth	-	1
AMC	-	1	Electronic R&D Command	-	2

NAVY (47)

OPNAV	-	1	NSWC	-	3
NPRDC	-	2	DTNSRDC	-	2
NOSC	-	5	Naval Medical Research Inst.	-	1
ONT	-	4	NTEC	-	1
NWC China Lake	-	3	Naval Air Propulsion Center	-	1
S&NWSC	-	1	ONR	-	6
NRL	-	13	NADC	-	4

AIR FORCE (9)

AFWAL	-	5
Human Resource Laboratory	-	1
AFOSR	-	1
FASC	-	2

TABLE IV.2 (Continued)

AGENCIES (24)

NSA	-	3
DARPA	-	4
NBS	-	11
DCA	-	1
DCEC	-	1
NASA	-	4

OTHER (4)

George Washington University	-	1
CNA	-	1
Sandia National Labs	-	1
University of Michigan	-	1

OBSERVERS (19)

OSTP	-	1	B-K Dynamics	-	1
CIA	-	4	DIA	-	1
DoE	-	1	IDA	-	1
ASME	-	1	NSF	-	1
USDRE	-	2	USD (P)	-	1
NISC	-	1	Eagle Research Group	-	2
USNA	-	1			
NSWC	-	1			

The second day of the Workshop was devoted entirely to the continuation of individual session work, resulting in the preparation of Protocols.

The morning of the third day the Workshop reconvened in plenary session for the Chairmen's overview briefings of selected ETs, and feedback/discussion of the Workshop and Delphi processes.

2. Protocols

At the Pre-Workshop Meeting with the session chairmen, comments were obtained relevant to a draft "protocol" to be followed by the Workshop members. This protocol was based upon an earlier version first developed by Eagle Research Group (ERG), Incorporated, in 1976-77 for use by DARPA to collect information on emerging technologies as part of the Bucy Report Implementation Program. The protocol was modified in 1983 and 1984 and used to solicit initial submissions for the COCOM Emerging Technologies Inventory, and used again in 1984 to collect and provide back-up information on emerging technologies for discussion at the January 1985 COCOM High Level Meeting. It was further modified in 1984 by ERG for use in the Militarily Significant ETs (MSET) project, and next amended with the approval of our ET Sponsor for use at the 1985 ET Workshop (see Appendix 10). Included within this Protocol were the definition of "emerging technologies," how the ETs were to be ranked, specific time estimates, use of quantitative descriptors and identification of related manufacturing know-how, status of development work and milestones, applications in terms of military use/products/processes, and, impact (changes to US military capabilities, and synergistic effects upon military capabilities when combined with other technologies). The technologies that were chosen by each of the sessions are listed in Appendix 11; the completed protocols are provided in Appendix 12.

E. RESULTS

This section introduces the results of the ET Workshop, looking at each of the seven mission areas and the process the panels went through in deciding on high priority technologies, summarizes their findings, and relates some of their conclusions and comments on the utility of the Workshop.

The participants in each session were asked to make an initial selection of about two dozen Delphi-identified technologies that appeared to be of potential importance for their area of application. They were then to pick a "top half," and then further split the top half in roughly two parts. The top quartile is thus of highest priority or Category "A." The next quartile is Category "B," and the bottom half is Category "C."

For various reasons, the sessions often chose a large number of items from the Delphi Survey, and then combined them or renamed them, to obtain a different aggregation. In some cases, completely new items were added and chosen as high priority (listed in Appendix 13).

1. Command, Control and Communications

The C^3 session focused on communications technology, ADP hardware, computer languages and software, electronic devices, and the command process. The session's procedure for finding the top priority emerging technologies started with selecting items from the Delphi-originated list and adding other items known to the Workshop participants to be of high interest. The session then developed the criteria for prioritizing these technologies into Categories "A," "B," and "C." The objectives sought among these C^3 ETs included:

- endurability/survivability of equipment and personnel;
- computer and communications security;
- interoperability;
- economy and affordability;
- force multiplier; and
- responsiveness.

Next, this session selected the high priority ETs for consideration, and assigned individuals to write protocols on specific ETs. These protocols were then passed among the members for comments, after which the session discussed and decided upon final prioritization.

Of those C^3 related technologies chosen from the Delphi list, about 80% fell into these four categories:

- communications, radar and signal processing;
- computers;
- electronic materials and devices; and
- robotics, automation and machine intelligence.

The C^3 participants found this process useful for planning, but it was clear that the C^3 subject is too large for a small group (24 members). The C^3 session objectives (above) oriented ET selection toward devices and hardware, with other kinds of technology not addressed. Also, there was some concern among the participants about those topics not considered by the session (surveillance, remote sensing, weapons systems, and life sciences). Although some of these topics have a direct bearing on C^3 operations, they were not addressed because of the limited time at the Workshop, the finite amount of expertise represented in the session, or in some cases because another session at the Workshop covered the same topic. In addition, the C^3 session found that there were certain limitations on the process. Most notably, many of the inputs from the Delphi Survey were of limited value to Workshop participants because the information provided was often incomplete.

The C^3 session members represented a wide variety of DoD and other governmental organizations:

- OSD
- DCA
- NASA
- DARPA
- Navy
- Army
- DoD CSC (Computer System Command)

The following list gives the 16 category "A" (top 25%) technologies selected by the C^3 session, with the eight highest priority ETs given first.

Category "A" technologies (top 25%):

- High-performance battery technology;
- Distributed automatic control of communications networks in hostile environment;
- Automatic generation of software from natural language;
- Parallel processing technology;
- Distributed data processing;

- Ultra-low-loss fiber optics;
- Automated image recognition and classification;
- Speech recognition;

- Design principles to improve reliability of electronic systems;
- Automatic allocation of functions between men and machines;
- Threshold logic for decision making with incomplete information;
- Decision support systems for military decision making;
- Compact high power, compact mm-wave antennas;
- Automatic mapping of signal processing algorithms in high level language into VLSI configuration;
- High-performance A-D and D-A converters; and
- Computer languages appropriate for parallel processing.

2. Directed Energy

The Directed Energy session examined power supplies for photon and particle beams, as well as the generation, forming, and directing of beams. Strategic Defense Initiative (SDI) weapons and Surveillance, Acquisition, Targeting and Kill Assessment (SATKA) were included in the initial evaluation of technologies, but Kinetic Energy Weapons (KEW) were excluded. The technologies initially chosen were ranked using two criteria. The first was relative importance to the Strategic Defense Initiative. Second, the session determined in what sense the technology is emerging. In other words, whether feasibility and scalability have been demonstrated, whether the time scale for production is within the 15 year maximum used in the definition of emerging technology, and whether the technological development is highly dynamic or emerging slowly.

The following procedure was used in choosing and prioritizing the Directed Energy technologies. The session first reviewed the list of Delphi-identified ETs for candidates, eliminating those not related to directed energy and those which would be covered by other sessions; this step left 18 technologies. Next to be eliminated were those "old" technologies which are slowly evolving over time (e.g., large optics, Delphi ET #F-11). Almost all of the remaining technologies were in the Directed Energy section of the Delphi, but the session also considered metal matrix composites (#I-6) and coherent gamma ray sources (#J-6). The session renamed and made more general what they considered to be overly specific ETs and combined those which were closely related to one another. For example, coupled resonators (#F-9) and laser phased arrays (#F-10) became coherent locking of lasers. This iteration yielded 10 emerging technologies.

The session then focused and renamed ETs that were not specific enough, and ranked the ETs, as listed below. (Note: These results are based upon the assumption that directed energy weapons are not necessary for the success of SDI, but that directed energy for SATKA is necessary.)

Category "A" technologies (top 25%):[1]

- Prime power (E, N);
- Metal matrix composites for space structure (E, N);
- Electron beams (E, N, *);
- Artificially structured materials for pulse power switching (E, N); and
- Neutral particle beams (N).

Category "B" technologies (next 25%):

- Coherent locking of laser beams (E);
- Nonlinear phase conjugation techniques (E);
- X-ray lasers--nuclear driven (E, *);
- Short wavelength lasers--non-nuclear (E); and
- Free electron lasers.

The session found that the definition of emerging technology needs improvement, specifically in terms of feasibility demonstration and "when available for inclusion in product or process." The choice of an unclassified forum for discussion of the technical issues surrounding directed energy impeded effective justification for the rankings and limited the description of potential military applications. Further, the participants found the Delphi inputs to be of limited value because of their lack of depth and detail.

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1. Key to notes on emerging Directed Energy technologies:
   (E) - Qualifies as an emerging technology
   (N) - Necessary for success of SDI
   (*) - Discussion at the session was limited by security considerations

3. Manufacturing

For the purposes of identifying relevant emerging technologies at this Workshop, manufacturing was defined by the session members to include its contributions to and involvement in the entire process starting with product development, through design and production, and ending with support and maintenance. There are three key elements in this range of activities. First is the unit process: those activities that take place on the shop floor; making and inspecting the product, from machine to cell level; and, executing the entire manufacturing plan, as well as the actual production of the product. The second key element involves manufacturing systems, i.e., planning, scheduling, control, allocation of resources, etc. This element implements and supports the manufacturing plan. A third element in the process is intelligent information handling: keeping track of past and current data and projections. In its most general sense this element is an abstract representation of the physical manufacturing operation. With this explanation of the scope of the ET Manufacturing session understood, the work of this session proceeded.

In choosing ETs, the most important consideration was potential payoff for DoD in terms of cost (life cycle or acquisition), performance, quality (yield and reproducibility), flexibility, and responsiveness. Other criteria were return on investment; how well the item fits the definition of an emerging technology; how long it would take for implementation; whether this ET represented a new capability or opportunity and responds to a current need; and, whether another session at the Workshop would cover it.

Below are listed Category "A" technologies for manufacturing, with the three highest priority ETs given first.

Category "A" technologies:

- High speed, high capacity computers;
- Advanced sensor development;
- "Intelligent processing" concepts;
- Autonomous machine vision/image recognition;
- Man-machine interactions;
- Manufacturing systems integration;
- Processing of limited/non-error-free data sets;

- Decision support system; and
- Muscle-like mechanical actuators.

Seventy-five percent of those technologies chosen as high priority (Category "A" or "B") items came from three Delphi categories:

- computers;
- electronic materials and devices; and
- robotics, automation and machine intelligence.

Precision engineering, a field not mentioned in the Delphi results, was also identified as an important emerging technology.

The Manufacturing session also found that the Delphi information was too sparse, perhaps because the research community has very limited involvement in the full spectrum of manufacturing. Nor was there a combination of members within the session to address all aspects of manufacturing technologies; therefore, certain areas could not be addressed.

The consensus of the Manufacturing session was that the next ET Workshop should include a session devoted exclusively to emerging technologies in materials.

4. Mission Support - Biotechnology

The Biotechnology session examined a number of technologies that would use biological materials or processes, including technologies that might provide protection against agents of biological and chemical warfare. The session assigned seven technologies to Category "A":

- Sustained release and targeted delivery of materials, e.g. drugs;
- Organisms that could metabolize materials of military interest;
- Organisms that could counter biodegradation of structures;
- Biotechnological means of decontaminating personnel and equipment exposed to CBW agents;
- Prophylactic/therapeutic compounds to counter CBW agents;
- Biologically-based techniques for separating materials; and
- Biologically-based techniques for manufacturing materials.

The Delphi Survey did not identify the last two technologies on the list, which were added by the Workshop participants. The second technology on the list was identified by the Delphi Survey, but Workshop participants redefined it.

The Workshop participants noted important applications of targeted delivery systems other than the well-known one for drug delivery. These included sustained release of protective coatings to reduce maintenance requirements and use of biochemical reactions with very high specificity to trigger very sensitive and selective detectors.

The participants discussed several possible applications of genetically engineered organisms, including organisms that would selectively attack materials that play key roles in components of military systems and organisms that would remove undesirable materials (for example, toxins) from the environment. The participants considered development of organisms that would protect military structures and materials against biodegradation and biocorrosion to be a very high-priority goal (along with development of improved inorganic materials that would provide similar protection).

Workshop participants thought that biotechnology could contribute to the development of better, operationally effective means of decontaminating personnel and equipment in CBW environments. In particular, they identified microencapsulated enzymes as promising decontamination agents that should be examined and developed in the near future. In addition to providing means of destroying CBW agents in the environment, participants thought that biotechnology could contribute to the development of better antidotes and prophylactics to protect people exposed to CBW agents. New monoclonal antibodies and prostaglandins (along with new chemical detoxicants) appeared to be promising candidates for this function.

Participants identified mass-produced antibodies as excellent candidates to enhance, and in some cases supplant, existing physicochemical techniques of separating desirable materials from complex mixtures. (The techniques supplanted may include some that employ the older biotechnology of enzymes.) The participants thought that biological processes might also produce novel materials, including new plastics and adhesives, cheaply and efficiently.

This Workshop session chose a broad range of high-priority technologies, reflecting the very broad range of applications in which emerging biotechnologies are likely to have significant impact.

5. Mission Support - Human Factors

This session examined emerging technologies that improve human and systems performance to maximize mission readiness and combat performance in manpower and personnel, training and simulation, human factors engineering, and cognitive sciences. The major criteria in choosing technologies were:

- impact of the technology vs. risk of development;
- whether the timing of development fits the ET definition; and
- whether the benefits of the technology outweigh the cost of the development.

Although some balance in technical areas was attempted, OSD recommended that the Delphi Survey emphasize hard sciences. Therefore, human factors areas were not comprehensively dealt with in the Survey. To overcome this deficiency, the Workshop participants added significantly to the nine technologies chosen from the Delphi Survey (most from robotics, automation, and machine intelligence), the participants added 33 more (in education and training, manpower and personnel, simulation and training devices, and human factors engineering). After eliminating those items which did not fit the definition of an ET, the session aggregated the remaining ETs to achieve approximately the same level technology on the basis of the applications, while minimizing overlap. The session divided the list of ETs into two halves, and assigned individuals to write protocols on the top half. The session as a whole evaluated the completed protocols, and then prioritized them into the first and second quartiles, as listed below. These ETs follow three main themes: expert systems; automated manpower, personnel and training design tradeoff; and combat training simulation.

Category "A" technologies (top 25%):

- Intelligent computer-aided instruction (D)[2];
- Decision aiding systems (D);
- Image generation/display (N); and

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2. Key to Human Factors technologies:
   (D) - ET identified in Delphi survey
   (N) - ET newly identified at the Workshop

- Performance prediction and assessment (N).

Category "B" technologies (next 25%):

- Embedded systems for training and job aiding (N);
- Computer-aided design for manpower, personnel and training (N);
- Realistic combat simulation (N); and
- Remote robotic devices (D).

This session participants believed that the quality of the Workshop output could have been enhanced by allowing more time for review of the responses and development of protocols, polling a larger, more diverse sample of technologists, defining emerging technology more clearly, and providing more detailed Delphi inputs.

6. Mobility

The scope of the Mobility session encompassed surface (land and water) vehicles, as well as air, undersea, and space transport, and looked specifically for technologies that increase capability and survivability, improve availability, and reduce costs. Out of approximately 50 items from the Delphi initially under consideration, 32 were chosen to be of top priority, with some of these incorporated together. Most (85%) of these fall into one of four technological fields:

- combustion, propulsion and energy;
- fluid dynamics;
- macroscopic materials; and
- robotics, automation, and machine intelligence.

The 12 Category "A" technologies are:

- Advanced engine technology;
- Engines with low IR signatures;
- Fuel cells for vehicle propulsion;
- Reduced observables;
- Active control of sound;
- High temperature non-metallic materials--novel processing methods;
- Automatic vision systems;

- Man machine interface;
- Automated speech understanding;
- Robotic task manipulators;
- Control of vortex flow in air and under water; and
- Supersonic combustion for high mach number air breathing propulsion.

Several items of interest from the Delphi list were not chosen as high priority ETs for one of a number of reasons. In some cases the Delphi items appeared to express "need statements" rather than technologies; in others the items did not have adequate supporting information; and, several of the Delphi-identified technologies were judged to have emerged already. (Unfortunately, we do not have a record of the ETs so identified.)

7. Search and Surveillance/Electronic Warfare

The session on Search and Surveillance/Electronic Warfare examined its subject from three different perspectives: (1) escalation of conflict, with measures, countermeasures, and counter-countermeasures; (2) examination of the carrier or medium, looking at both acoustic and electromagnetic radiation; and, (3) targeting, here understood to include search, detection, identification, tracking, and fire control. Criteria for initial selection of ETs were: confirmation that the listed item represents an actual technology, and not just a requirement; that it is currently moving forward in research and development; and, that this technology is directly related to S&S/EW. The session chose 41 items from the Delphi list, 85% of which were from four categories:

- communications, radar, and signal processing;
- computers;
- electronic materials and devices; and
- robotics, automation, and machine intelligence.

The following list gives the top 25% of the ETs chosen by S&S/EW, with the five highest priority ETs listed first.

- High performance A/D conversion for recording and signal processing (e.g., 16 bits - 5 MHz; 8 bits - 500 MHz);
- Technologies associated with reduced signature military platforms;
- Integrated optical sensors/analog/digital processing elements in a single chip focal plane array;

- Growth of three- and four-component compound semiconductors of desired (specified) characteristics;
- Image recognition and artificial intelligence;

- Framework for modular signal processors;
- Multi-signature decoys;
- Active control of sound;
- Melding of best features of digital and analog computing, including optical processing to get extremely high computation rates on many parallel channels;
- Heterostructure superlattices of layered materials
- High density, two-dimensional, solid-state arrays for imaging in the visible and infrared;
- Optical fiber technology;
- Optimum allocation of decisions and actions between humans and machines;
- Highly parallel architecture based on systolic chips;
- Monolithic GaAs and III-V related components;
- Fast wave amplifiers as efficient high power sources of coherent millimeter and sub-millimeter wave radiation;
- Low-probability of intercept (LPI) and long range air frame classification radar for airborne intercept;
- Chemical bonding agents; and
- High speed computers--parallel and array processors in compact portable modules.

S&S/EW session membership was composed primarily of representatives from the Navy and Army, with a few members from the National Bureau of Standards and the Air Force. The range of expertise included radar (microwave, millimeter wave, infrared), ESM/ELINT, SIGINT, DF, "smart weapons," antisubmarine warfare, acoustics, and C^3CM.

F. WORKSHOP CONCLUSIONS

There was substantial overlap among the technologies chosen as high priority by the C^3, Manufacturing, and S&S/EW sessions, with 32 ETs chosen independently by at least two of those three sessions, and 10 chosen by all three sessions as high priority projects.

Another striking result of this Workshop is that one technology area stood out as being judged of exceptional importance for future technological developments. "Robotics, automation, and machine intelligence" was the most widely chosen of all the subject areas: 20 of the 21 Delphi-identified items in this category were chosen as at least "C" technologies, with 16 chosen as high priority ETs. Nearly half (nine) were chosen by more than one session.

Also, the temporal definition of emerging technologies varied from one session to another, as demonstrated by the following data. The sessions were asked to provide estimated date of availability for inclusion in a product or process for each of the high priority ETs. Table IV.3 summarizes the average availability date for the highest priority ("A"--top 25%) technologies, which range from 1990 for Mission Support-Biomedical Technologies to 1999 for Directed Energy.

Table IV.3

AVERAGE AVAILABILITY DATE FOR HIGHEST PRIORITY ("A") ETS OF EACH SESSION

(Calculated from the information in the Workshop protocols)

1990	-	Mission Support--Biomedical Technologies
1991	-	Search and Surveillance/Electronic Warfare
1992	-	Command, Control and Communications
1994	-	Mobility
1996	-	Mission Support--Human Factors
1996	-	Manufacturing
1999	-	Directed Energy

Two of the technological areas, on the other hand, prompted little interest among the seven sessions at the Workshop. Of the 12 Delphi items in chemistry and catalysis, only two were chosen as high priority ETs. In remote sensing, oceanography and meteorology, two of 25 items were chosen. (The Sponsor did not wish environmental ETs to be addressed by this initial Workshop. A separate Workshop on Environmental Sciences, held at NRL in November 1985, evaluated this area. The results of this Workshop are provided and assessed at Volume III of this Integration Report.)

Table IV.4 shows which Workshop sessions chose at least five items from the Delphi categories as high priority ETs.

Table IV.4

DELPHI TECHNOLOGICAL CATEGORIES WITH HIGH CONCENTRATION OF TOP PRIORITY ETS

	MISSION AREAS					
	C^3	DE	Mfg.	Mission Support (Biomed & Human Factors)	Mobil.	S&S/ EW
DELPHI CATEGORIES						
Biotechnology				X		
Chemistry and Catalysis						
Combustion					X	
Communications	X				X	
Computers	X		X			X
Directed Energy		X				
Electronics	X		X			X
Fluid Dynamics					X	
Materials					X	
Optics/Lasers			X			
Remote Sensing						
Robotics	X		X	X	X	X

CHAPTER V
SYNTHESIS OF THE SURVEY AND WORKSHOP RESULTS

A. INTRODUCTION

The primary objective of the SAIC ET work to date has been to provide a general direction to the search for important areas of emerging technology that are potential candidates for increased emphasis by the DoD research community. The previous chapters have described the Delphi and Workshop procedures toward that end. In this chapter, we discuss the synthesis of the results of these procedures in identifying an initial set of candidate topics for in-depth studies. These studies will provide up to date information on which OSD can base policy decisions such as new technology base initiatives. Preliminary to the discussion of the synthesis process, we will discuss some important background information available from other studies, and indicate how they can contribute to the synthesis.

There has never been a simple prescription for allocation of R&D funds, since both the payoff and the cost are usually educated guesses, at best. In many cases, the payoff has been orders of magnitude greater than anticipated, because the development has led to entirely new applications (the pervasive influences of office reproduction equipment and the microcomputer are obvious examples).

Low energy laser technology is an area that was supported from its infancy by the DoD and has resulted in a number of important applications. Table V.1 shows the present areas of investment in this technology while Table V.2 gives the applications of these lasers and identifies the DoD systems in which they are being used. While in hindsight it is obvious that laser technology is verv important to the DoD, it was not that long ago when serious questions were being asked in regard to support of laser technology because few "useful" applications could be foreseen.

This should make us approach our problem with caution, with the recognition that there will of necessity be a large measure of intuitive judgment in collective decisions on research and development projects. Additionally, other factors not included here,

Table V.1

LOW ENERGY LASER TECHNOLOGY AREAS OF INVESTMENT

PRIMARY LASERS	LASER COMPONENTS	EFFECTS
SOLID STATE LASERS (optically pumped)	OPTICAL ELEMENTS	PROPAGATION (atmospheric)
SEMI-CONDUCTOR LASERS (current excited)	DETECTORS	PROPAGATION (intracavity)
GAS LASERS (discharge excited)	MODULATORS AND SWITCHES	DAMAGE
DYE LASERS (optically pumped)	FLASH LAMPS	SAFETY
CHEMICAL LASERS	INTEGRATED OPTICS MATERIALS	TARGET SIGNATURES
GAS DYNAMIC LASERS	OPTICAL FILTERS	
FREE ELECTRON LASERS	GRATINGS	
	ELECTRO-OPTICAL DEVICES	
	ACOUSTO-OPTICAL DEVICES	
	ELECTRONIC COMPONENTS	

SECONDARY LASERS

- RAMAN
- FREQUENCY DOUBLING/TRIPLING
- FOUR WAVE MIXERS
- PARAMETRIC OSCILLATORS

Table V.2

LOW ENERGY LASER APPLICATIONS

CURRENT MAJOR AREAS OF INVESTMENT

FIELD OF APPLICATION	LASER	DOD SYSTEMS
		1ST GENERATION SYSTEMS
FIRE CONTROL AND WEAPONS GUIDANCE	SOLID STATE	RANGEFINDERS
		DESIGNATORS
		2ND GENERATION SYSTEMS
	GAS	BEAMRIDERS
		ACTIVE SMART SENSORS
		LASER/MM WAVE HYBRIDS
LASER SURVEILLANCE/RADAR	GAS, SEMI-CONDUCTOR	PASSIVE/ACTIVE FLIRS
		3-DIMENSIONAL AIRBORNE LINE SCANNERS
		UNDERWATER DETECTION
COMMUNICATION AND INFORMATION TRANSFER	SEMI-CONDUCTOR	HIGH BANDWIDTH FIBER-OPTICS COMMUNICATION
TRAINING AIDS	SEMI-CONDUCTOR	BATTLEFIELD SIMULATION

Table V.2 (continued)

FIELD OF APPLICATION	LASER	DOD SYSTEMS
REMOTE LINE-OF-SITE METEOROLOGY	SOLID STATE	VISIBILITY, AEROSOL, AND WIND FIELD MEASUREMENTS
CHEMICAL/BIOLOGICAL AGENT/ EXHAUST DETECTION	GAS, SEMI-CONDUCTOR	LIDARS
ADVANCED LASER SENSORS	GAS SEMI-CONDUCTOR	LASER GYROS; ACOUSTIC SENSORS
DATA PROCESSING	SEMI-CONDUCTOR	FOURIER TRANSFORM VIA INTEGRATED OPTICS/ACOUSTO-OPTICS DEVICES/ OPTICAL STORAGE
LASER MATERIAL PREPARATION	SOLID STATE GAS	MARKING, CUTTING, DRILLING, ANNEALING
OCM	SOLID STATE/GAS	

such as assessments of adversary threats, intelligence data, and specific Service needs, affect final decisions to allocate resources. The premise under which we have been proceeding is that it is desirable to factor into the decision process as much of the informed, intelligent intuition as can be uncovered. We are fully cognizant that it is not complete.

In the context of the DoD, we are confronted with the necessity of trying to combine the judgments of the technical innovator (who may be naive about the real feasibility of application of his proposed innovations) with the judgments of the military user (who may be suspicious of changes in the accustomed modes of operation). The user may also be skeptical about high technology, generally and specifically.

In this effort, we are focusing on the earliest portions of the Research, Development, and Acquisition cycle, where the outcomes are the most speculative, but also possess the potential for very high "payoff." These efforts, usually funded out of the Technology Base Programs (6.1 and 6.2 budget categories), are also at the interface between the military establishment and the innovators in academia and industry. This integration is particularly important since the investment made by the DoD in Technology Base Programs has been shrinking over the last 15 years as a fraction of the DoD's RDT&E program (see Figures V-1 and V-2).

To capture research supported by all Federal agencies as well as private funds, we used the Delphi process as a means to bridge gaps between the DoD and non-DoD research communities. We have found it instructive to examine a prior (Defense Science Board) attempt to bridge this interface, discussed in Section V.B. We also discuss, in Section V.C, the insights that can be gained by other, more recent studies. Finally, Section V.D will describe some emerging technology aggregates that appear to be promising candidates for in-depth study.

B. DEFENSE SCIENCE BOARD STUDY ON THE TECHNOLOGY BASE

Some interesting and important ideas on how to prioritize the DoD technology base effort are coherently discussed in the report of the DSB 1981 Summer Study Panel on the Technology Base. Their emphasis on technologies that can make an "order of magnitude" difference in capabilities is excellent guidance for this current effort. The DSB also listed a group of "integrating factors" that appear to permeate their scenarios for future wars:

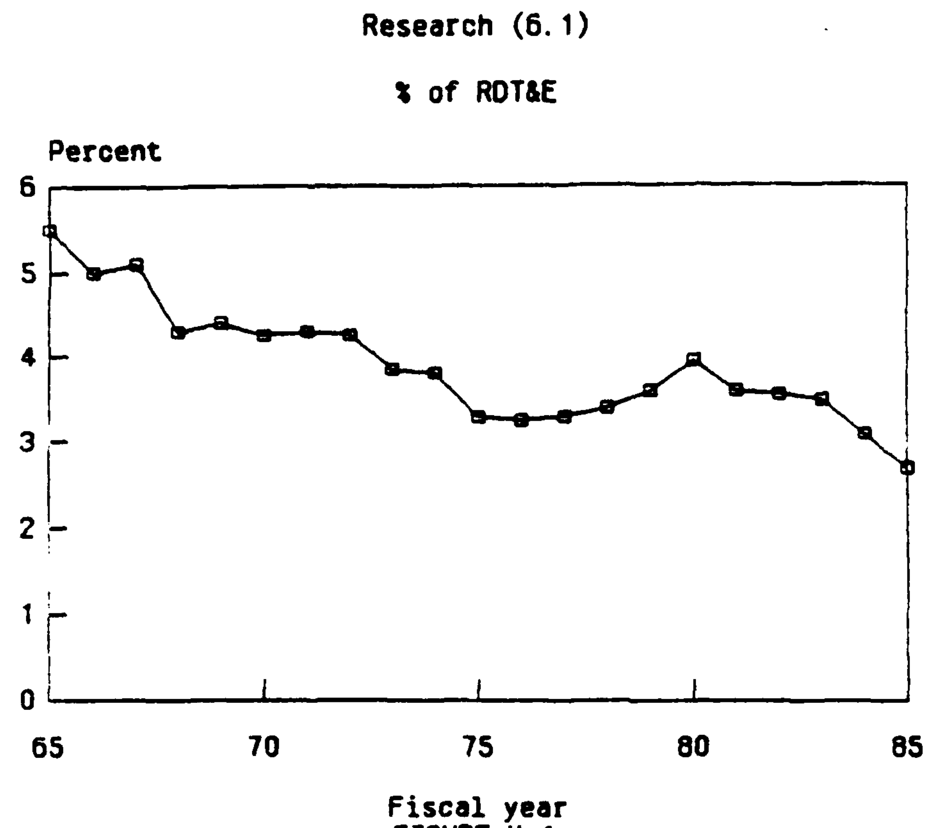

FIGURE V-1

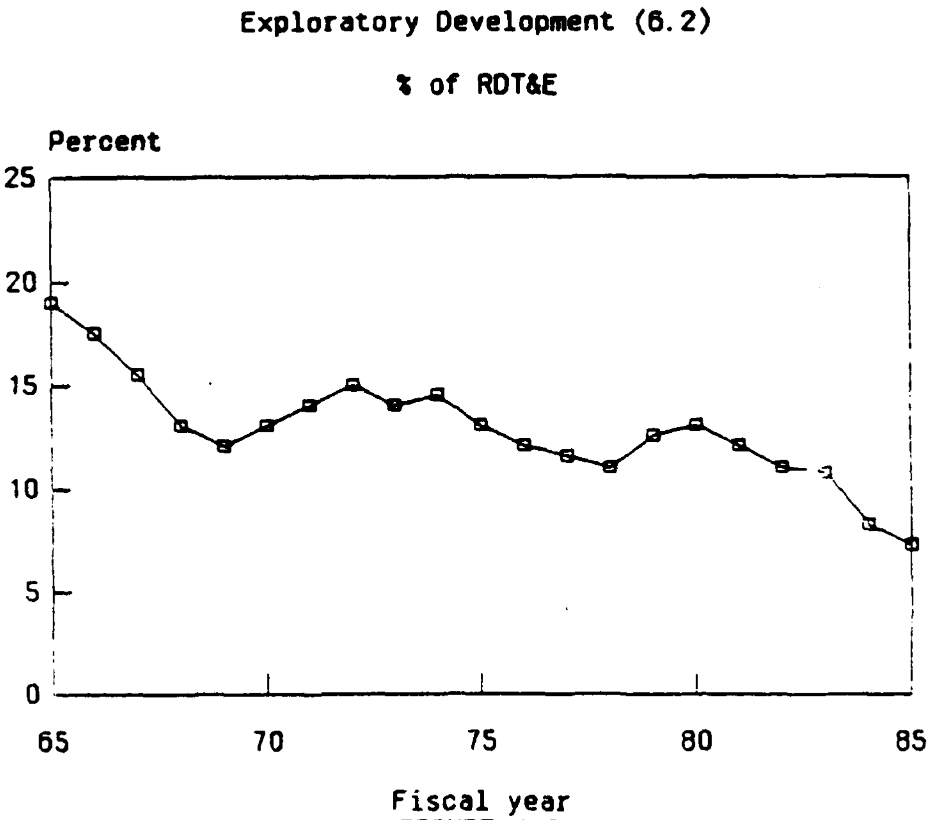

FIGURE V-2

- Sustained Operations;
- Continuous Threat Location/Track;
- Real-Time Information Management;
- Counter Threat Target Acquisition;
- Integrate "Eyeball and Trigger";
- Secure, Jam-Resistant, Mobile Communications;
- Dispersed, Small Units;
- Transparent Complexity;
- Equipment Availability/Reliability; and
- Operations in Extreme Environments.

This list can be useful in addressing how the "technology aggregates" to be discussed below might fit into a wide set of scenarios. However, it cannot be viewed as a comprehensive "checklist." The DSB report also develops a set of "technical requirements" from the scenarios, but we will not consider that set in this report since our focus is more on research than on technology. Our "window" is at an earlier stage than that considered by the DSB. On the basis of the two sets of criteria, the DSB panel developed a list of 17 "order of magnitude" technologies, as follows:

- Very High Speed Integrated Circuits;
- Stealth;
- Advanced Software/Algorithm Development;
- Microprocessor-Based Personal Learning Aids;
- Fail-Soft/Fault Tolerant Electronics;
- Rapid Solidification Technology;
- Machine Intelligence;
- Supercomputers;
- Advanced Composites;
- High Density Monolithic Focal Plane Arrays;
- Radiation Hardened Advanced Electronics;
- Space Nuclear Power;
- High Power Microwave Generators;
- Large Space Structures;
- Optoelectronics;
- Space Based Radar; and
- Short Wavelength Lasers.

Several of these categories contain Delphi-identified technologies that were chosen by Workshop participants, as will be discussed below. It is also worth noting that the items listed represent varying levels of technology aggregation or specificity.

C. OTHER RELEVANT STUDIES

At one time, OSD produced various documents intended to provide road maps through individual technology areas and the DoD programs in each area. The most recent of these documents, the Technology Area Descriptions, have not been produced since 1981. There are, of course, individual program descriptions within the DoD computerized data base system. Rather than attempt to scan this data base, we were able to use a directory of "Militarily Significant Emerging Technologies" prepared in 1985 by Eagle Research Group (ERG). This report identified DoD-sponsored projects that should be monitored for possible export control. It is incomplete (i.e., the Army is not represented by any submissions) and the individual technology descriptions vary widely in depth and scope. Nevertheless, it is a useful adjunct to the Delphi-identified technologies (which are incomplete because the knowledge of the members of the particular group who responded is not complete). The areas chosen by ERG to categorize their ETs, and the number of ETs in each category are shown in Appendix 14. Not all of those categories correspond directly to the SAIC Delphi categories, and the large "Miscellaneous" category contains some items analogous to SAIC items.

We are also in the fortunate position to have available literature on applied science in both the Soviet Union (FASAC) and Japan (JTECH). The FASAC reports can help us identify areas where we may have the opportunity to increase the lead time for important new technologies to become available for inclusion in our military systems, while both JTECH and FASAC reports can be used as a source of data on the pace of foreign activity in a general area. These correspondences will be cited below when relevant, although it is expected that they will play a more major role in providing information for the in-depth assessments.

D. IDENTIFICATION OF KEY TECHNOLOGIES

As described in the discussion of the Workshop, there are multiple examples of individual Delphi-identified technologies that were identified by more than one session as being of top priority. In addition, many of the protocols aggregated individual Delphi-identified technologies into a combination that would be most beneficial to the specific applications area. We now attempt to use this information to perform a different kind of grouping--to describe "emerging technology aggregates" that are candidates for in-depth studies. Criteria for aggregation include a desire that the overall aggregate represent a "significant" area of technology with promise of wide and important applications. On the other hand, the aggregate should be small enough, with sufficient commonality among items, that the area is amenable to detailed technical analysis by a relatively homogeneous group of experts. In-depth studies need not be constrained to examine only those specific technologies identified by the Delphi/Workshop process. The in-depth study should be guided, however, by the applications and priorities generated during the Workshop, subject to refinement during the actual study by additional user input. We list in Table V.3 candidate sets of technology aggregates that, subject to further refinement, could serve as topics for in-depth study. The remainder of this section is a description of each of these topics and of their possible applications.

Table V.3

HIGH-PRIORITY EMERGING TECHNOLOGY AGGREGATES

Computer Parallel Processing Technology
Robotic Vision, Image Recognition and Classification
Decision Logic and Allocation, With Man-Machine Interaction
High Temperature Structural Materials
Portable Power Supplies
Speech Recognition and Natural Language Understanding
Electrooptic Technology
Advanced Software Generation
Signal Processing Technology
Non-silicon Electronic Materials and Optoelectronics
Reduced Signature Technology
Advanced Engine Technology
Biologically Based Processes
Simulation Technology and Training

Computer Parallel Processing Technology

The Delphi Survey resulted in five individual technology submissions addressing different proposed hardware implementations of highly parallel computer processing, plus a submission for development of computer languages appropriate to parallel processing. The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(E-2)*	Parallel processing based on optical communication between N processors and M memories (not necessarily chip-to-chip optical interconnections)
(E-3)	Parallel processing based on novel interconnect hard wired (non-optical) schemes (e.g., "cosmic cube" architecture)
(E-4)	Architecture analogous to neuron connectivity in mammalian brains
(E-6)	Highly parallel architecture based on systolic chips
(E-7)	Computer language which is really appropriate for parallel processing
(E-14)	Melding of best features of digital and analog computing, including optical processing, to get extremely high computation rates, with appropriate dynamic range, on many parallel channels

Almost all of these were chosen by one or more Workshop sessions as being of high priority.

There is general agreement in the computer R&D community that--unless some fundamentally different and as yet undemonstrated hardware technology comes along--the rapid advances in instruction execution rates that we have witnessed are going to slow down precipitously, and the only way to make orders of magnitude advances in throughput will be by highly parallel processing (there are also situations in which parallel processing is desirable because of a diversity of data input nodes). Several approaches to the problem have been suggested, and it is an actively developing field, clearly on the verge of emerging in one or more forms into serious development.

Examples of the approaches proposed range from novel interconnect hard wired (non-optical) schemes (e.g., "cosmic cube" architecture), to architecture based on neuron connectivity in mammalian bodies. The former is thought to be available for application

* The numbers in parentheses are the identification numbers for the 237 Delphi-identified ETs. For the complete list, see Appendix 6.

within the next five years and its value is judged to be very high. The value of the latter is also very high and its potential impact perhaps higher, but its availability is predicted to be around the turn of the century or later since the pathway to accomplishment is less certain.

Other research that falls within this category and needs further investigation includes: very wide band multiplexing; rapid synchronization of CPUs (increase of at least an order of magnitude over present system); large I/O capability from distributed memory sites; and general algorithms for problem subdivision (partitioning algorithms). Particular emphasis has also been placed on systolic array architectures as a device to achieve higher efficiency in numerical linear algebra computations.

From the protocols developed at the Workshop, the following evidently important uses for parallel processing were identified by members of the C^3, S&S/EW, and Manufacturing sessions:

- In C^3 for complex systems (e.g., SDI);
- Data base management systems;
- Decision making and forecasting (e.g., weather forecasting);
- Unit processes, CAD/CAM, advanced manufacturing systems; and
- Signal processing and pattern recognition.

Robotic Vision, Image Recognition and Classification

This is one of several major areas identified by at least five of the Workshop sessions. The reason for its popularity is that the range of technologies represented here potentially can either make an order of magnitude difference in combat effectiveness or provide new options for addressing current or future defense missions. This is consistent with the 1981 DSB study identification of "Machine Intelligence" as one of the 17 order of magnitude technologies.

The three Delphi-identified technologies that address this area are:

Delphi #	Technology
(L-1)	Automated image recognition and classification through use of AI techniques
(L-2)	Vision for robotic systems
(L-3)	Autonomous weapons vision with automatic target recognition

Needed developments range from those currently envisioned to be available within several years, like an order of magnitude increase in computer performance, to significantly more reliable algorithms. The former is achievable by designing more efficient hardware and improved architecture. The key is also to integrate AI and pattern recognition techniques and to use them on the new generation of supercomputers. Parallel processing of information would also significantly help in being able to handle large amounts of data from a number of remote locations. Mobile robots also have great potential, but a number of problems have to be resolved first, for example, photometric stereo and extended Gaussian images.

The important potential applications for the three ET technologies above range from the prosaic though important process of selection/rejection of parts in the "factory of the future" to support of several SDI components, particularly the high-leverage boost and mid-course systems. The general categories of military applications mentioned in the Workshop are:

- super smart weapons;
- battlefield management;
- surveillance and reconnaissance;
- industrial automation; and
- remote sensing with real time analysis.

Other applications include inspection systems in semiconductor manufacturing, automotive manufacturing, telecommunications and a host of other high technology industries.

Decision Logic and Allocation, with Man-Machine Interaction

This aggregate encompasses several technologies related to decision aiding and allocation, as well as the more general class of technologies for man-machine interactions, which have applications in many fields. Chosen by five of the seven Workshop sessions, these technologies will have a major impact on a wide range of defense-related activities. With increasing automation and the phenomenal growth in information available to and needed by military decision makers, such technologies will play an important role in command centers, automated cockpits, nuclear power reactors, and other areas.

The five Delphi-identified technologies that address this area are:

Delphi #	Technology
(L-4)	Optimum allocation of decisions and actions between humans and machines in a man-machine system
(L-16)	Threshold logic for decision making in situations of incomplete information
(L-17)	Decision support system for military decision making (e.g., for efficient task assignment and efficient procurement procedures: user-friendly; information storage, retrieval; processing and display to support decision making)
(L-18)	CAD/CAM-type systems with prediction models of human performance
(L-19)	Man-machine mutual monitoring loops

These technologies involve hardware, software and general management system design. Specifically, they include:

- Electroencephalographic (EEG) sensors for monitoring alertness of operators;
- Data processing--high volume, high speed (100 MIPS) filtering and; manipulating;
- Data transmission--local area networks ($\sim 10^8$ Hz) transport and control protocols;
- Displays--large screen displays with resolutions 2000 x 2000 lines or better;
- Improved data correlation--algorithms to correlate/associate better data from diverse sources;
- Knowledge-based systems--AI techniques for higher levels of automation;
- Large-scale data bases, and distributed data base management--distributed operating systems, data base access, queries, and updates involving different data bases;
- Generic expert system building tools;

- Interactive human-computer interface that allows efficient dialogue; and
- Decision methodology for optimal system architecture to retain overall system property of human reasonableness and reversibility, with the machine component accounting for limitations in human capacity or stress tolerance.

(Another related technology, natural language understanding for human-computer interface, is discussed under "Speech Recognition and Natural Language Understanding," below.) In addition to the technological milestones outlined above, information scientists must learn how to partition overall problems into solution techniques that can be automatically scanned to choose optimum hardware/ software utilization, and must investigate who does what kind of activity best.

Decision aiding and allocation could be incorporated into any large scale enterprise, commercial or military: corporate planning and management; production scheduling; intelligence analysis; forecasting; and, relieving information overload faced by military commanders. Optimum allocation of decisions between man and machines could reduce training requirements for personnel and reduce the probability of human error.

These technologies are rapidly advancing, with recent developments in "influence" type chips and in ternary computers. The various technologies should be ripe for incorporation in a system between 1992 and 1995.

High Temperature Structural Materials

Fighter and commercial aircraft are currently using more and more non-metallic materials. A similar trend will continue in missiles as well. Throw-away high performance ceramic engines are also being developed in the hope of providing additional options to US defense planners. Applicability of these technologies need not be limited to aircraft and spacecraft, but could be extended to land and sea vehicles, and to guns.

New alloys promise enhanced performance in a number of areas, including: superior corrosion resistance; high strength, particularly at elevated temperatures, increased wear resistance; better oxidation resistance; and reduced critical material content.

The seven Delphi-identified technologies that address this area are:

Delphi #	Technology
(I-3)	Fiber-reinforced ceramics for high-strength applications at high temperatures
(I-6)	Metal matrix composites for high strength-to-weight
(I-9)	Novel methods of preparation of large single or polycrystalline materials, usually prepared as ceramics, such as SiC, AlN, etc.
(I-12)	High temperature ceramics that are tough, durable, and impact resistant
(I-16)	Inorganic polymer systems for high temperature structural applications
(I-17)	Oxidation resistant lightweight composites for performance above 3000°F
(I-20)	Chemical approaches to formation of high purity, crack resistant ceramics

The value of these technologies is judged to be high to very high (three and four on our Delphi scale) and availability ranging from within five years to up to 10 years (particularly for some of the more exotic uses, as needed for SDI applications).

Polymers are also expected to play an important role, not only in electronic materials processing but also in structural materials. Japan is currently making a major thrust in polymers and the United States is expected to be challenged for leadership in this area in the next several years. More information is to be expected on this in the next ET Integration Report, including input from the recently-concluded SAIC JTECH panel on Advanced Materials.

Needed developments include better understanding of bonding mechanisms and the role of interfaces of dissimilar materials, improvement in fracture toughness, reduction in cost (particularly on a mass production basis), control of grain boundaries, and identification of fiber-matrix materials capable of withstanding very high temperatures. Also critical is the need to have a better controlled process (with real-time artificial intelligence capability) for materials fabrication.

Specific applications for these new materials include:

- high temperature gas turbines and adiabatic diesels;
- lightweight components for missiles, rockets, aircraft, spacecraft, guns, furnace lines;
- hypersonic aircraft;

- "throw-away" high performance engines;
- SDI and space station components; and
- high temperature chemical processing lines.

Portable Power Supplies

Portable power supplies are important to many military operations, including C^3, Search and Surveillance, the Strategic Defense Initiative, and Mobility.

The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(C-16)	Long lived batteries for space applications
(C-17)	High power, high energy density batteries
(C-18)	Efficient, inexpensive fuel cells
(C-19)	Efficient, inexpensive photovoltaic cells
(I-10)	Conducting polymers for "all-plastic" batteries and lightweight electronics
(N-3)	Prime power

The list above details the basic technologies for power supplies identified by the Delphi Survey and at the Workshop. Such energy sources will be useful in satellites, air-dropped and submarine-launched buoys, and for powering directed energy weapons. Low-drain electronics (e.g., VHSIC) powered by new batteries could make undersea surveillance, arctic warfare, and space operations more efficient.

For high power, high energy density batteries, a variety of materials were considered (e.g., nickel/aluminum, iron/air, iron/silver, lithium, and nickel/cadmium). The specific characteristics of these couples are examined in a protocol of the C^3 session.

Another more experimental medium, conducting polymers, shows substantial potential in lightweight and rugged RFI and lightening shielding and enclosures, X-ray transparent electrical conductors, current and signal transport, anti-static packing of electronic devices and precision bearings, and as an electrolyte in solid state batteries. Using them could reduce the radar cross section of military platforms. Conductive polymers have low density, can have high porosity, and have electrical conductivity ranging from 10^{-12} to 10^{2} $(\Omega\text{-m})^{-1}$.

Demonstration of a working battery and of anti-static packing using conductive polymers has already been accomplished on an experimental basis. Before they can be incorporated in an actual working device, the following technical milestones must be reached:

- doped polymers that are stable in the presence of moisture; polypyridyl and polyphthalocyanine are two of the most promising;
- processing techniques for these materials; and
- ways of trapping species permanently.

The March, 1985 report of the Innovative Science and Technology Office of the Strategic Defense Initiative Office points out that high energy density batteries are a necessary component of the space based defense systems (p. 11). Of particular interest to the Directed Energy session at the Workshop are 100MW prime power systems storing gigaJoule-level energy, which could be used for powering directed energy weapons. Generators at the 100 megawatt and gigaJoule storage levels are predicted to be available by 2005.

Speech Recognition and Natural Language Understanding

Speech recognition and natural language understanding were identified in the Delphi Survey as rapidly emerging technologies of high value to the military and civilian sectors. This evaluation was endorsed by the DoD participants at the Workshop, where five out of seven mission area sessions chose it as a high priority ET.

These two technologies were grouped on the basis of their common artificial intelligence base and range of applications, but will be considered separately below. The two Delphi-identified technologies that address this area are:

Delphi #	Technology
(L-6)	Automatic understanding of speech of a specific individual
(L-7)	Automatic understanding of speech of a general class of individuals

Speech systems with a limited vocabulary, requiring clear pauses between words and tied to a single speaker are available today. Speaker-independent systems with large vocabularies, capable of dealing with continuous speech, requires these advances in hardware, software, and linguistics:

- custom VLSI chips to obtain computational speeds required (100x improvement in computer power);
- faster search algorithms (10x improvement in algorithms);
- increase in knowledge of invariant relations among linguistic features;
- codification and utilization of constraints imposed by the sound patterns of a language; and
- utilization of the context of knowledge of the subject of discourse in interpreting the sound.

Speech understanding systems could serve as front ends to natural language understanding systems that acquire data transmitted by voice in C^2 operations. Such systems, with 20,000-word, unlimited syntax, speaker-independent capability could be available by 1990 to handle discrete speech, and by the year 2000 for continuous speech.

Natural language understanding (NLU) systems will play an increasingly important role in man-machine interactions. They are usually characterized according to:

- the size of the domain of discourse;
- the frequency of misinterpretation;
- the level of training required of users; and
- the level of interactive verification of understanding that is required.

NLU systems with limited domain, some errors, some training and some verification have already been built, but are very limited in scope.

The capability of inference of current expert systems (~hundreds of rules) is insufficient. An order of magnitude increase in inference power might handle speaker-dependent continuous speech in a domain of several hundred words. Very powerful heuristic algorithms will be required to go beyond that.

Parallel processing is likely to improve the efficiency of such systems, but major advances are needed in maintaining consistency in large knowledge bases and in acquiring innate knowledge (i.e. common sense). NLU systems with high levels of capability will be available by the year 2000.

These systems could be used by machine operators, fighter pilots, and executives; could yield innovations such as speech typewriters, control-less cockpits, and verbally-instructed remote/robotic devices. Speech recognition and natural language understanding technology in military management systems could allow a substantial reduction in clerical manpower and a major increase in efficiency.

Together with image recognition and device manipulation mechanisms, NLU technology will be part of remote/robotic devices that have applications in environments hazardous to humans, and could give the US military an important tactical advantage in broadening the range of environments that could be penetrated for military purposes.

Electrooptic Technology

This area is of major importance to telecommunications, large scale computing and other applications where metallic wires are used presently, as well as for advanced replacements for electronic components. The use of fiber optics and optical computers is envisioned in all SDI system proposals. Additionally, as commercial vendors are moving toward a "total" fiber-optic environment, most DoD platforms of the future will have fiber optics instead of copper wires. This will reduce weight, and also provide the wide band of frequencies needed to perform additional tasks.

The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(J-1)	Ultra-low-loss fiber optics
(J-3)	Optical fiber sensors for measurement of physical parameters
(J-4)	Optical fiber sensors for measurement of chemical properties
(J-11)	Mid- and far-infrared optical fibers of low loss
(G-4)	Integrated optical sensors/digital processing elements in a single chip focal plane array
(N-2)	Advanced communications switching techniques

As fiber-optics will be utilized more, so will the need increase to merge electronics and optical devices, most preferably on a single chip. While more applications will utilize all optical systems, for the next 10 to 20 years there will continue to be utilization of hybrid systems, and optics and microelectronics will have to be compatible and function side by side.

Specific developments are needed to bring this technology to full maturity. Some developments are expected within five years, such as better fiber optical materials (low loss, improved fiber drawing, near-zero dispersion over a wider frequency band). The integration of optics and electronics is expected within 10 years, and fully integrated, optical computers even further out.

Specific applications range the full gamut of defense and commercial applications. These include, as mentioned previously, SDI applications related to C^3I, factory of the future applications, most telecommunications systems, remote sensing, and real time processing at remote locations. A desire for more secure communication systems plus EMP protection also play a key role in driving this technology.

Advanced Software Generation

The ultimate goal of all computer systems should be to extend and enhance man's abilities. An important bottleneck has been and promises to be software generation. The Delphi-identified technologies that address this area are:

Delphi #	Technology
(E-1)	Automatic generation of software from "natural language"
(E-11)	Computational methods using numerical and symbolic data

Other evolving technologies are relevant to the advancement of software generation technology. These include disciplines of programming methodology, software testing and verification, and proof-of-algorithms theory. Methods for prediction and evaluation of software performance are particularly needed for highly complex defense systems, such as those proposed for the Strategic Defense Initiative. The automatic program generation ET has as its "front-end" component one of the most difficult technologies in artificial intelligence: natural language understanding. Because the domain of a program-writing program should be very broad, little advantage can be taken of economies that are possible in such systems when the universe of discourse of the interpretation system can be limited. For the "back-end" of the automatic program generation ET progress is needed in fundamental questions such as how knowledge about situations, facts and problem-solving strategies can be acquired (learned), represented and organized for later use in present and analogous (future) situations.

Signal Processing Technology

Applications for this technology cross all strategic and tactical weapon systems and could have a major effect upon any SDI concept. Improvements in signal processing system performance were judged to be of high priority in the areas of search and surveillance, electronic warfare, and communications.

The five Delphi-identified technologies that address this area are:

Delphi #	Technology
(D-2)	Optimum adaptive processing of limited and/or non-error-free data sets
(D-3)	Automatic mapping of signal processing algorithms described in high level language onto specific multiprocessor architecture or VLSI configurations
(D-6)	High performance A/D conversion for recording and signal processing (e.g., 16 bits-5 MHz; 8 bits-50 MHz)
(D-7)	Coherent signal processing systems for active/passive spatially dispersed sets of sensors
(D-11)	Low-cost, high speed A-D/D-A with built-in filtering

These technologies involve both hardware and software improvements. The desired hardware improvements are generally in the direction of greater bandwidth capability; the most likely near-term route to achievement is through the use of GaAs technology developments. In addition, there is a perceived need for rapid production of application--specific ICs for signal processing systems. The desired software improvements prominently include new techniques for combining data, often including aspects of "expert system" requirements for compensating for errors or gaps in data. Also desired are new means of combining different kinds of data, and/or data from several locations.

Non-silicon Electronic Materials and Optoelectronics

Virtually every facet of current and future defense capability relies on electronics. The DSB study of 1981, referred to earlier, listed 17 technologies as being the most important for vigorous pursuit within DoD. Of those 17 technologies, 12 are either directly electronics related, such as VHSIC, supercomputers, etc., or depend initially on improved electronic systems, such as space based radar, radiation hardened electronics, machine intelligence, etc. In other words, new and improved electronics materials are essential building blocks to many, if not most, new DoD options in leveraging US technological advantage over our potential adversaries. While most of today's electronic systems are based on silicon technology, it is projected that new materials, particularly the III-V compound family, are the materials of the future. The competition for technological advantage is intense. The Japanese have made significant progress and will continue to strive to gain in this area, as reported by the Opto-microelectronics JTECH panel. The Soviets are also cognizant of the importance of this new area. They have given up any attempt to mount major efforts in silicon research, focusing most of their research on III-V materials. This is more fully detailed in the 1984 FASAC report on Soviet Microelectronics which is being updated by a new FASAC panel in 1987.

The eight Delphi-identified technologies that address this area are:

Delphi #	Technology
(G-1)	Synthetic nonlinear optics materials custom-designed for specific applications (e.g., optical computer elements)
(G-3)	Molecular-scale electronic circuit elements and conductors
(G-4)	Integrated optical sensors/digital processing elements in a single chip focal plane array
(G-6)	Growth of three- and four-component compound semiconductors of desired (specified) characteristics
(G-12)	Bulk crystal growth of GaAs, other III-Vs, and semiconductor alloys
(G-14)	Heterostructure superlattices of layered materials
(G-19)	Optical read/write recording devices
(I-1)	Conducting polymers for "all plastic" batteries and lightweight electronics

New polymeric materials are expected to play an important role in these technologies, particularly playing a role in providing good substrate materials.

Expected developments based on these technologies are too numerous to mention here and range in availability from 1986 to the year 2000 and beyond. For example, mass-produced GaAs IC chips for specialized uses (e.g., microwave frequencies) are just around the corner, to be available either from Japan or domestic vendors.

Recent research developments in non-helium temperature superconductors could prove to be extremely important in Josephson junction technology. In fact, a number of technologists now predict that Josephson junctions, rather than GaAs, will provide the building blocks of supercomputers in the year 2000.

Molecular-scale electronics utilizing quantum effects, on the other hand, are just now being researched, and full proof-of-principle prototypes are some time away. Wires as small as 80A have been prepared and there is a need for 10A lithography. Making chip features small addresses only half the problem, since present IC architectures will not be adequate in the ultra small regime.

The range of application for this technology is exceedingly large and could potentially provide the technology needed to continue the exponential growth of the number of devices per chip well through the next 20 years.

Reduced Signature Technology

Reduction of radar, visible and acoustic signatures of defense platforms has been of high priority as a countermeasure since the beginning of wide use of radar and other sensors by the United States and the Soviet Union. With the development of lasers, reduced signatures of platforms at all frequencies has become a high-priority goal of US military developers. The technologies include paints, materials, and design configurations of systems. Better active and passive control of all electronic and acoustic signals, to reduce radar, IR, or acoustic cross sections, could significantly change and improve US military capabilities. Improved recognition of decoys from our adversaries and development of better US decoys may also be possible with several of the emerging technologies identified in this study.

The nine Delphi-identified technologies that address this area are:

Delphi #	Technology
(C-9)	Aircraft engines with low infrared emissions
(D-12)	Multi-signature decoys (including visual holograms)
(D-13)	Active control of radar cross sections
(D-14)	Materials with reduced radar and IR signatures
(D-15)	Antennas with low radar cross sections
(D-16)	Air vehicles with very low observable signatures through multidisciplinary technology integration
(D-18)	Active control of radiated sound
(D-19)	Active control of reflected sound (target strength)
(N-21)	Low-probability-of-intercept (LPI) long range air frame

The above topics have had ongoing active research programs for several years, but much more is needed to fully utilize these phenomena, particularly under various conditions at all electromagnetic frequencies. Advanced technologies for reducing acoustic signals are in their infancy, but could have major military impact.

Advanced Engine Technology

Research on near-adiabatic engine technology has as its goal the minimization of heat loss, reducing cooling system requirements, with improved compactness, fuel economy, reliability/maintainability, and survivability. This research is focused in four areas:

- high temperature materials;
- high temperature friction and wear phenomena;
- unconventional lubrication techniques (including solid lubricants--both in slurry and surface coating form); and
- near isothermal heat transfer phenomena.

Areas where work must be done in order to move this technology into production and use include:

- improved processing of ceramic and composite materials;
- improved and more reliable component NDE inspection techniques;
- methods of reducing high temperature material costs;

- methods of producing high-temperature slurries in a repeatable and economically feasible manner; and
- improved advanced materials analysis method.

The three Delphi-identified technologies that address this area are:

Delphi #	Technology
(C-2)	Spark-ignited diesel engines, usable with a wide spectrum of fuels
(C-3)	Near-adiabatic diesel engines utilizing high-temperature ceramic components (and no circulating coolant)
(C-10)	Stable high-temperature lubricants for near-adiabatic diesel engines

Adiabatic diesel engine technologies identified by the Delphi respondents were picked up by the Mobility session, and recognized as a high priority ET which potentially offers qualitative improvement in ground, naval, and air vehicles in terms of compactness, fuel economy, weight reduction, signature reduction, multifuel characteristics, and design flexibility.

At high levels of performance, with respect to power output, compactness and surface temperature, this technology could be available for advanced military vehicles by about 1990. Early versions of some parts of these technologies (low output-100 lbs. per square inch BMEP) are technically feasible now and have been put in production by the Japanese (ceramic pistons, exhaust parts, turbochargers, and cylinder heads in automobile engines) and by the Germans (ceramic exhaust port on all 1985 Porsche 944 turbocharged engines). This technology will continue to be driven by a combination of military need and commercial payoff.

Biologically Based Processes

This aggregation of ETs includes a variety of processes and techniques. To make the range of technologies represented more manageable, we will consider first just those processes that counter toxic agents and waste. Custom-designing bacterial strains that metabolize harmful compounds have already been successfully genetically engineered. For example, a strain of Pseudomonas that efficiently degrades toxic phenolics to non-toxic products has been demonstrated in the laboratory and is currently being field tested at several USAF bases. But in general, major problems remain for scale-up from laboratory to industrial operations, particularly in batch culture, regulation of substrate feed, and collection of metabolized products. When such manufacturing systems become practical, the organisms will find application in waste-treatment, in life-support systems (for removal of toxics from confined environments and production of needed life-support substrates, such as oxygen), in detoxification/decontamination, and in production of scarce but militarily significant materials. Such systems should be available starting in *1990, depending on the specific substrate.*

In addition to detoxification, organisms will also be employed in separation of materials, possibly yielding new plastics, adhesives, coatings, pharmaceuticals, and light-weight construction materials. Separation techniques involving immobilization of an antibody using physical or chemical means, will allow separation of an antigen-antibody complex. These techniques have proven to be successful in laboratories, and have already been employed in the separation of materials which are difficult or impossible to separate by other means. Scale-up of these techniques, and an increase in antibody affinity and efficiency, will take place in the next two to five years.

The six Delphi-identified technologies that address this area are:

Delphi #	Technology
(A-5)	Development of organisms that will metabolize militarily relevant toxic waste products
(A-6)	Development of organisms that will counter the biodegradation of materials
(A-7)	Bioprocess technology for materials
(B-5)	Bio-catalysis with immobilized enzymes
(B-9)	Enzyme catalysts that work in non-aqueous environments
(N-3)	Biologically based materials separation techniques

Other separation technologies, such as *affinity chromatography*, high pressure liquid chromatography, and electrophoresis, need substantial improvement (200-400%) for large scale operation, but should be available within five years.

Simulation Technology and Training

Technology that was not identified in the Delphi Survey but received strong interest by the Mission Support-Human Factors session was simulation technology and advanced training techniques. Simulation technologies are basically hardware, and can be discussed on the basis of technical characteristics. But these technologies can contribute to an entire system of training that was also examined at the Workshop. In considering these five technologies, we will proceed from the more "device-oriented" to those that are closer to recommendations of redesign of military activities.

The military has been significantly hampered by a lack of realistic combat environment for training and testing of individual skill proficiency and operational capability. New technologies that can provide realistic simulations of combat are emerging and hold the promise of improving the combat effectiveness of personnel, material, units, and doctrine, and greatly reduce training costs. Improved combat simulation technology includes emerging technologies involving lasers, rapid information processing, interactive computers, graphic imagery, visual displays, helmet-mounted displays, and AI-based combat protocols. Most of these are already used in low fidelity simulations, but more research on these ETs is needed to support high fidelity simulations; such high fidelity simulations could be realized by 1990.

The five Delphi-identified technologies that address this area are:

Delphi #	Technology
(N-12)	Intelligent computer-aided instruction
(N-13)	Image generation/display
(N-14)	Cognitive abilities/aptitude measurement and performance prediction/assessment
(N-15)	Embedded systems for training and job aiding
(N-17)	Combat environment simulation technology

One particular subset of these technologies that received special attention at the ET Workshop was image generation/display. While extensive gains in computer image generation (CIG) have been achieved, more advances are needed for inexpensive on-line techniques for providing wide angle, high brightness, high contrast, high resolution visual presentations in a simulator, with high scene detail at close range and dynamically changing visual content caused by object motion or surface effects, as well as training with sensor input. Four specific technologies that show promise for a solution to these problems are:

- helmet-mounted displays (using laser projectors, fiber optics, or miniature CRTs);
- area of interest high-resolution inserts or variable acuity lenses;
- high intensity color projectors; and
- hybrid approach to sensor simulation based on computer generated/ synthesized imagery (CGSI) or on cell texturing.

The first three should be available for inclusion in simulators in 1990. CGSI will be ready for application between 1990 and 1995, and will find use in many military platforms, including aircraft, surface and subsurface ships, and ground installations.

The second group of training-related ETs aim at reducing the cost and increasing the effectiveness of a wide range of training and education programs. The use of AI based computer instruction could increase the efficiency of training by placing human instructors in roles that they can perform best, effectively increasing the instructor/ student ratio. Such systems could monitor student performance, evaluate student progress, diagnose conceptual "bugs" in the students' understanding, and control the sequencing of instruction, providing remediation where necessary. In order for such a technology to be realized expert systems must be developed that emulate:

- a subject matter expert with extensive knowledge domain;
- a student whose knowledge becomes progressively less primitive; and
- a tutor possessing knowledge of good instructional principles.

According to the Mission Support protocol submitted, such expert systems are 15 years away from application.

A more near-ter technology is the measurement of cognitive abilities and aptitude, and prediction or assessment of performance. Human abilities and aptitudes heretofore ignored, such as information handling speed, can predict performance in situations important to military operations. By using these tests the military can improve the selection, classification, training, and assignment of personnel and optimize the use of human operators. Such testing and prediction could be based on recent advances in cognitive psychology and computerized testing capabilities. Basic models are now in place, but five to seven years will be needed for development and validation of these new testing techniques.

The third "technology" singled out by the Human Factors session recommended incorporating on-line training and performance testing in all military systems for enhanced operating efficiency and effectiveness. Such built-in training would overcome the drawback of school-based training (e.g., constraints on frequency and duration of schooling because of cost and manpower losses). Recognition of the need for better training in the military and the drawback of exclusive reliance on school-based training should lead to a change in approach. Engineers and training experts will have to work together on instructional development and system design for the final product. Embedded training technology has already been demonstrated in many computer systems and by 1988 will be available for incorporation in military systems.

15. Summary

The preceding synthesis has identified 14 ET aggregates as an initial set of candidate priority topics for in-depth studies.

For some program or budget planning purposes, it may be desirable to further group the aggregates. For example:

Group	Applicable ET Aggregates
I--(Digital) Computers/Software	Computer Parallel Processing Technology
	Decision Logic and Allocation, With Man-Machine Interaction
	Speech Recognition and Natural Language Understanding
	Advanced Software Generation
II--Electronics and Electromagnetics	Robotic Vision, Image Recognition and Classification
	Electrooptic Technology
	Signal Processing Technology
	Non-silicon Electronic Material and Optoelectronics
	Reduced Signature Technology
III--Materials and Processes	High Temperature Structural Material
	Portable Power Supplies

Group	Applicable ET Aggregates
	Advanced Engine Technology
	Biologically Based Processes
IV--Simulation and Training	Simulation Technology and Training

Considering these ET aggregates by group may facilitate their application to selected DoD programs, such as university research centers. But a distinct disadvantage of such an approach is to lose inter-group visibility of individual ETs.

A rough breakdown of the application areas for each of the ET aggregates is in Table V.4, based on information in Delphi Survey responses and Workshop protocol.

Table V.4

APPLICATIONS OF ET AGGREGATES

Aggregates \ Applications	Intelligence	Communications	SDI	Search & Surveillance	ASW	Radar/Microwave	Operations-manpower issues	Mobility (Vehicles)	Stealth	Power storage & transmission	Structures	Industrial processes	Chemical warfare	Weapons	Warfighting
1. Computer parallel processing	X	X	X	X	X		X	X				X			X
2. Robotic vision, image recognition	X		X	X				X				X	X	X	X
3. Decision allocation, man-machine interaction	X		X				X	X				X			X
4. High temperature structural materials			X					X			X		X		
5. Portable power supplies	X	X	X					X		X					
6. Speech recognition, natural language understanding	X	X					X	X				X			X
7. Electrooptics	X	X	X	X		X			X			X		X	X
8. Advanced software generation	X	X	X	X			X					X			X
9. Signal processing		X	X		X	X			X						
10. Non-silicon electronic and optoelectronics		X	X	X								X			X
11. Reduced signature technologies	X		X	X	X	X			X					X	X
12. Advanced engine technology								X							
13. Biologically based processes											X	X	X		
14. Simulation and training				X			X	X							X

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CHAPTER VI

EVALUATION OF EMERGING TECHNOLOGIES PROGRAM EXPERIENCE TO DATE

A. OVERALL GOALS

To recapitulate, the purpose of the Emerging Technologies Program is to assist the DUSD (R&AT) in developing a coherent Department of Defense strategy for technology base investment, by identifying those rapidly advancing/emerging technologies of potential importance to national security. A four-phase repeatable approach is being followed:

(1) A multi-round Delphi Survey of 100 nationally recognized technical experts;

(2) A Workshop attended by 120 DoD application experts, to review the emerging technologies identified by the Delphi experts;

(3) The integration of phases (1) and (2) by SAIC into a detailed assessment report (this Integration Report being the first), adding inputs from SAIC's Foreign Applied Sciences Assessment Center (FASAC), Japanese Technology Evaluation Program (JTECH), Global Technology Evaluation Center (GTEC), and in-house SAIC technology expertise; and

(4) Based upon the recommendations in the ET Integration Report, a series of in-depth assessment panels (as tasked by DoD) to address the highest priority "ET aggregates" in terms of technological risk, cost/benefit analyses, vulnerability issues, synergisms of ETs, and the like.

Because this ET Program represents a unique effort to assist DoD research investment strategy formulation, several approaches to each of the above phases--and indeed, different phases--could be chosen. The purpose of this Chapter is to describe why the ET Program chose our particular approaches to the Delphi and Workshop, and the benefits and known limitations of these approaches.

B. THE 1985 ET DELPHI EFFORT

1. Breadth Versus Depth

In order to obtain a "world view," unconstrained by classification or by specific organizational preferences, an initial list was prepared of over 200 nationally eminent technical experts as candidates to participate in the four-round ET Delphi. This list was then culled to embrace the broad spectrum of areas of science and technology potentially relevant to national security, while avoiding unnecessary duplication of expertise. This revised 130-candidate list then formed the basis for requesting the participation of individual respondents; 102 accepted.

It is recognized that literally thousands of experts could be sought, before an encyclopedic treatment of emerging technologies might be approached; however, time and budget limitations would not permit that level of effort. Our emphasis for the first iteration of the repeatable ET Program was upon breadth rather than depth; if the "depth" approach had been initially chosen, far fewer areas of technology could have been addressed. In the next iteration of this four-phase assessment program, depth should be emphasized more and breadth reduced, to search from a different viewpoint for those ET aggregates of highest importance.

2. Bias Versus Size of Sample

Chapter III provided the names of the Delphi respondents, most of whom are immediately recognizable authorities in their field. It is to be noted that the vast majority of these experts work outside government--a purposeful selection in order to broaden inputs from as large a pool of US experts as possible. It also minimizes overt parochial interests skewing the identification of emerging technologies in individual responses to the Delphi Survey questionnaires. In addition, each of the respondents was requested to address only those technology areas in which they considered themselves to be competent.

This approach proved manageable, and resulted in the initial identification of 65 ETs by the Delphi "Test Group," whose input was then increased to 237 ETs by the larger group of Second Round respondents.

C. THE 1985 ET WORKSHOP

1. Classified Versus Unclassified Forum

An initial point of discussion among some Workshop attendees was, "Why is this process unclassified; couldn't more be accomplished at a classified forum?". In planning the 1985 ET Workshop this question was addressed, including the effects of classification requirements upon: the size of attendance; what lowest common denominator of clearance could have been agreed upon; how the "need to know" principle would have affected the size of discussion groups; and, most importantly, what increased benefit to the ET process would have accrued and would that benefit be of such import as to override the preceding concerns?

After considering these issues SAIC recommended, and the Sponsor approved, an unclassified Workshop forum.

2. Workshop "Dynamics"

Three comments are relevant, as background to the 1985 ET Workshop:

- Whenever a meeting of experts is intended to conduct objective deliberations, care must be given toward balancing membership to try and avoid predisposed majority, or inordinately vocal views.

- When 128 DoD experts are convened, representing various Service, laboratory and headquarters constituencies, one should expect coalitions of interests to be expressed. This certainly occurred during this Workshop.

- If one of the Services/laboratories/headquarters decides not to participate fully, fair representation of that organization's interests is not likely and should not be expected.

For future Workshops, SAIC recommends a similar "bottom up" solicitation of attendees from the Services, etc., in parallel with the official request from OSD to the participating parent organizations--but, this membership selection process should be given ample time to be completed, in order to assure the most representative attendance that is possible.

3. Suitability of the Process

As described earlier, the process chosen for this Program consists of successive, iterative phases: Delphi; Workshop; Integration; and In-Depth Assessments. In this instance, two of the Delphi rounds were completed prior to the Workshop. Several variations in the process could be considered in future iterations:

- Ensure completion of Delphi Rounds One, Two and Three prior to the Workshop, by scheduling the Workshop well in advance (i.e., four months, or more).

- Conduct a Fourth "Declarative" Round of the Delphi after the Workshop to address Workshop results.

- Vary the process markedly: conduct Workshop sessions first; write Protocols; use those Protocols as the basis for the Delphi Rounds One through Three; feed these results back to the sessions; digest the results; hold a second Workshop; feed the Workshop results back to the Delphi respondents; and then hold a final series of session meetings to conclude the process of identifying ETs.

In our experience, several approaches might be productive, some taking many more months than others to complete; the approach that SAIC is following has resulted in the production of a very large amount of data for DoD consideration, accrued in a short period of time. For future Workshops, however, we intend to ensure delivery of all Delphi data to the Workshop session Chairmen well in advance of the Workshop; distribution to selected members of various sessions could also be considered, because of the difficulties inherent in absorbing and addressing complex technology issues in the few days available at a Workshop alone.

4. "Needs Statements" Versus Defining Emerging Technologies

Other than the Test Group input of 65 ETs, the majority of the remaining 172 ETs tended to be "one-liners" (many of which were not addressed by sessions due to the absence of explanatory/supporting data). Therefore, the majority of the session chairmen, and many Workshop attendees, recommended that Delphi inputs consist of detailed descriptions of the ETs being cited. Also, in the view of several session chairmen, a number of the Delphi-identified emerging technologies represented "wishes," and not emerging technologies.

This latter dynamic proved most useful, in that it affirmed the purpose of the ET Workshop--to provide the means by which a DoD "filter" could be applied to the input from the outside Delphi experts. The correlation of high priority ETs identified by both the Delphi and the Workshop formed the basis for identifying candidate ET aggregates, as topics both for the follow-on in-depth assessment panels as well as for future ET Workshop sessions.

CHAPTER VII
PLANS FOR 1987 AND BEYOND

A. BACKGROUND

Conclusion of Round Three of the ET Delphi Survey, and analysis of its results and implications, provided the final data input for this Integration Report. The analyses and assessments included in this Report therefore represent the synthesis of the first three phases of the ET Program: Delphi Survey; Workshop; and Integration Report. The fourth phase, as described in Chapter II, is to conduct Sponsor-directed in-depth Assessment Panels, to analyze the highest priority ET Aggregates (described in Chapter V). The first such panel, "III-V Microelectronics," has completed its report. The second ET panel is assessing "Machine Intelligence/Machine Vision." Subsequent panel topics are to be selected by the Sponsor.

The ET Program is structured as a repeatable process, to address those areas for potential investment that were not included in this initial effort, as well as areas yet to be identified. All four phases can be repeated, or selected portions tailored to specific requirements. In either case, the major benefits to the Sponsor should result from Phase Four of the ET Program--the reports by the In-Depth Assessment Panels. The scope, contents and benefits to be derived from the Assessment Panel efforts are described below.

B. SCOPE OF ASSESSMENT REPORTS

Each ET Assessment Panel should:

- review in depth the world state of the art of the selected ET Aggregates;
- identify and gauge milestones/breakthroughs needed for Workshop-identified DoD applications; and
- provide recommendations for follow-on DoD/intelligence community actions.

The major topics of each ET Assessment Report should include:

- Substantiated identification of the ETs that should receive increased/ accelerated research investment(s).

- The evident importance of pursuing such investment strategies.

- Detailed assessment of the technological risks that may be obscured by the Delphi and Workshop predictions for the ET Aggregate(s) being assessed.

- A general assessment of relevant cost versus benefit issues.

- The importance of timing to successful investment in the specific aggregates.

- What ETs, if any, must precede the development of the subject ET.

- Synergisms of ETs within the Panel Report Aggregate (e.g., resultant, mutually supportive capabilities).

- Vulnerability issues, to include possible reactive countermeasures by adversaries, action-reaction cost spirals, inducing undesired technology responses, and the like.

- Incorporation of Human Factors and Environmental technologies pertinent to the ET Aggregate(s).

- Recommended investment sponsorship (e.g., Where in DoD? Elsewhere in Government? Industry? Leader/follower? Seed money?)

Table VII.1, at the end of this Chapter, further displays examples of representative, detailed contents of an ET Assessment Panel Report.

C. ASSESSMENT REPORT BENEFITS

Major expected benefits of the Assessment Panel reports include:

- the reports will be a unique part of a coherent OSD-directed effort to identify rapidly advancing technologies;
- the emphasis of each report will be directed to ETs of relevance to DoD;
- the selection of assessment ET Aggregates will be soundly based upon: inputs from outside experts (Delphi); DoD applications requirements (Workshop Protocols); other relevant SAIC experience (e.g., FASAC, JTECH, and GTEC); and this Integration Report;
- each in-depth assessment will be responsive to DoD near-term needs, via: tailored selection of the chairman and panelists; on-going guidance from DUSD (R&AT) Sponsor articulation of concurrent policy developments requiring ET input(s); and
- each report will provide responsive expert assessments of significance to the DoD investment strategy process.

Table VII.1

REPRESENTATIVE DETAILED CONTENTS OF AN IN-DEPTH ET ASSESSMENT

- Assess and describe research activities (including principal areas of emphasis) and the current state of the art achieved world-wide in the topical areas spanning the selected ET Aggregates.
- Identify the institutions and research teams here and abroad that are doing the most significant research from a technical, not quantitative, standpoint.
- Compare US state of the art with its major competitors, including the Soviet Union, by assessing trends in the level and intensity of effort (growing or waning); novel research approaches and techniques; and, degree of access to research instrumentation, e.g., computers.
- Extrapolate from current state of the art those furture emerging technologies and applications that might have high military, economic or policitcal impact, including considerations of technology transfer.
- Identify the milestones or subsequent achievements that can be expected in future research as checkpoints for later monitoring of progress in the field. Identify the most probable research teams achieving this result.
- Assess the impact and implications of US research accomplishments versus those accomplishments occurring in the Soviet Union.
- Identify areas of research in which there is an anomalous absence of work in the technical literature here or in countries giving the United States its major competition.
- Identify the funding agencies sponsoring this work in the United States, and estimate the level of effort.
- What is currently <u>not</u> being done to ensure the timely US pursuit of research necessary to produce a desired ET (specifics, by sub-topics).
- Identify areas of research which are outside the ET Assessment Panel's focus, but which might be important for a future panel to address (e.g., serendipitous findings).

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

A-D/D-A	analog to digital and digital to analog (computer conversion)
AFOSR	Air Force Office of Scientific Research
AFWAL	Air Force Wright Aeronautical Laboratories
AI	artificial intelligence
AMC	US Army Materiel Command
AMMRC	US Army Mechanics and Materials Research Center
ARO	Army Research Office
ASD	Assistant Secretary of Defense
ASME	American Society for Mechanical Engineers
BMEP	brake mean effective pressure
CAD/CAM	computer-aided design/computer-aided manufacture
C^2	command and control
C^3	command, control and communications
C^3I	command, control, communications and intelligence
CCM	counter-countermeasure
CEC	Civil Engineering Corps
CGSI	computer generated/synthesized imagery
CIA	Central Intelligence Agency
CIG	computer image generation
CM	countermeasure
CNA	Center for Naval Analyses
CRT	cathode ray tube
CSEC	Computer Security Evaluation Center
CW	continuous wave

DARPA	Defense Advanced Research Projects Agency
DCA	Defense Communications Agency
DCEC	Defense Communications Engineering Center
DF	direction finding
DIA	Defense Intelligence Agency
DoD	Department of Defense
DoD--CSC	Department of Defense/Computer System Command
DoE	Department of Energy
DSB	Defense Science Board
DTNSRDC	David Taylor Naval Ship Research and Development Center
DUSD (R&AT)	Deputy Under Secretary of Defense for Research and Advanced Technology
EEG	electroencephalographic
EMP	electromagnetic pulse
ERG	Eagle Research Group
ESM/ELINT	Electronic Surveillance Measures/Electronic Intelligence
ET	emerging technology
FASAC	Foreign Applied Sciences Assessments Center
GJ	gigaJoule
GNP	gross national product
GTEC	Global Technology Evaluation Center
IC	integrated circuit
IDA	Institute for Defense Analysis
I/O	input/output
IR	infra-red

JTECH	Japanese Technology Evaluation Program
KEW	kinetic energy weapon
LD	laser diode
LPI	low-probability-of-intercept
MIPS	million instructions per second
MSET	Militarily Significant Emerging Technologies
MW	microwave
NADC	Naval Air Development Center
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NDE	non-destructive evaluation
NISC	Naval Intelligence Support Center
NLU	natural language understanding
NOSC	Naval Ocean Systems Center
NPRDC	Navy Personnel Research and Development Center
NRL	Naval Research Laboratory
NSA	National Security Agency
NSF	National Science Foundation
NSWC	Naval Surface Weapons Center
NTEC	Naval Training Equipment Center
NVEOL	Night Vision Electrooptics Laboratory
NWC	Naval Weapons Center (China Lake)
ODUSD/R&AT	Office of the Deputy Under Secretary of Defense for Research and Advanced Technology
ONR	Office of Naval Research

ONT	Office of Naval Technology
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
OSTP	Office of Science and Technology Policy
OUSDRE	Office of the Under Secretary of Defense for Research and Engineering
RAM	Reliability, Availability, Maintainability
RFI	radio frequency interference
SAIC	Science Applications International Corporation
SATKA	surveillance, acquisition, targeting and kill assessment
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Office
SIGINT	signals intelligence
S&S/EW	search and surveillance/electronic warfare
USACE	US Army Corps of Engineers
USAMRDC	US Army Medical Research and Development Command
USD(P)	Under Secretary of Defense (Policy)
USDRE	Under Secretary of Defense for Research and Engineering
USN	United States Navy
USNA	United States Naval Academy
VHSIC	very high speed integrated circuits
VLSI	very large system integration

DISTRIBUTION NOTE

Recipients of Volume I of this report, who wish to receive a copy of Volume II (described at the Table of Contents), should send their request for Volume II to:

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