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THE DEPARTMENT OF DEFENSE

CRITICAL TECHNOLOGIES PLAN



**FOR THE
COMMITTEES ON ARMED SERVICES
UNITED STATES CONGRESS**

1 MAY 1991

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I.

SUMMARY

The purpose of the Department of Defense Critical Technologies Plan (DCTP) is to describe 21 technologies considered essential for maintaining the qualitative superiority of U.S. weapon systems and to outline an investment strategy to manage and promote the development of these technologies. The Defense Critical Technologies are the leading edge of the DoD Science and Technology (S&T) program. While all S&T efforts are fundamental to achieving continued improvement in military capabilities, the Defense Critical Technologies represent those technologies that are likely to set the pace of innovation in the development of advanced weapon capabilities and the evolutionary modernization of today's systems.

This third annual plan is more comprehensive than earlier editions. A new section has been added to document funding levels for individual Defense Critical Technologies for the relevant S&T Program Elements (PEs) (Annex A); moreover, the individual detailed technology plans (Annex B) provide greater detail on specific milestones and technology objectives, as well as a more comprehensive discussion of related private sector and non-DoD government programs. The plans also include assessments of international technology developments and trends.

The 1991 plan reflects a substantially increased level of participation from the Services, industry and interested Federal agencies, particularly in the generation of the detailed technology plans. The contributions of the Aerospace Industries Association, the Electronic Industries Association, and the National Security Industrial Association were particularly valuable. The Department of Energy, the National Aeronautics and Space Administration, the National Institute of Standards and Technology (Department of Commerce), and the National Science Foundation provided extensive information regarding relevant non-DoD programs and helpful comments on specific technology plans. In addition, the 1990 Defense Science Board (DSB) summer study provided a solid basis and framework for this DCTP. A wide range of DoD organizations were also integral to the preparation of this plan, particularly the Joint Staff and the DSB. The contributions of all are acknowledged.

The Secretary of Defense stated his top priorities on several occasions. These priorities not only recognize the complexities of national security and future uncertainties in the world, but also provide objectives for research and development in DoD. These priorities are:

- Quality Personnel
- Technological Superiority
- Efficient Acquisition
- Robust Nuclear Posture and Strategic Defense
- Versatile, Ready, Deployable, Sustainable Force
- Continued Maritime Superiority
- Reserve Forces and Mobilization
- Special Operations Forces

The DDR&E has established three streams that seek to:

- 1.) Provide for the orderly, evolutionary improvements in weapon systems, their subsystems, and support systems, such as the training, logistics, and defense industrial base

infrastructure. These improvements must be responsive to future security threats and environments. The Services are the primary agents for these evolutionary technology changes.

2.) Generate innovative, highly leveraged breakthrough technology and insert this technology efficiently into our military capability. Here the Defense Advanced Research Projects Agency (DARPA) plays a major role, as does the Strategic Defense Initiative (SDI) program, the Balanced Technology Initiative, and the research organizations of the military departments.

3.) Seek technology trump cards (to be played every 5 to 10 years) to sustain long-term dominance in the technological arms race. Recent examples of such trump cards are stealth aircraft; older examples include the atomic bomb and the Polaris System. Trump cards bring about major shifts in how we think about and conduct war.

The S&T program is the principal vehicle for implementing these three streams. The Critical Technologies program focuses primarily on stream two, and contributes to streams one and three. The Critical Technologies program consists of 21 Defense Critical Technologies. They are listed in Table 1.

This year's planning process confirms the priority placed on these technologies by DoD in the 1990 Critical Technologies Plan. These technologies were originally selected on the basis of their contributions to maintaining the superiority of U.S. military weapon systems, primarily through their leverage on key subsystems. (The Defense Critical Technologies are discussed further in Chapter II. Brief technology plan summaries are presented in Chapter III, and the full technology plans are presented in Annex B.)

Tables 2A and 2B below show planned spending levels for the Defense Critical Technologies in FY 1991 as well as annual budget totals for FY 1992-97. These figures incorporate relevant funding from the DoD S&T program, including the Strategic Defense Initiative Organization (SDIO), which is a strong contributor to many of the Defense Critical Technologies. (Defense Critical Technologies funding is summarized further in Chapter IV and detailed at Annex A.)

The overall funding levels and objectives for development of the Defense Critical Technologies reflect the FY 1992 President's Budget. Recent management attention, including the 1990 Defense Management Review (DMR) initiated actions, has resulted in a strong emphasis on support for the Defense Critical Technologies, an emphasis that is reflected in these funding levels. Despite the fact that budget constraints will cause overall DoD RDT&E spending to decline over the coming years, funding levels for the Defense Critical Technologies have significantly increased in FY 1992 from the FY 1991 budgeted request and will remain stable or increase slightly. DoD's commitment to the Defense Critical Technologies will remain strong. The Defense Critical Technologies already represent a substantial focus within the combined S&T/SDIO technology development budgets, accounting for approximately 35 percent of projected FY 1992 spending. This share is projected to increase to approximately 40 percent of the total S&T/SDIO technology development budget by FY 1997. Without SDIO, the percent of critical technologies for FY92 is approximately 52%, a significant increase over the FY91 requirement.

DoD recognizes the need to ensure that its S&T resources — and particularly its Defense Critical Technologies budgets — are focused on high-payoff technologies that meet the most pressing current and emerging military needs. DoD is conducting an ongoing appraisal of the Defense Critical Technologies programs to ensure that the Services and Defense Agencies maintain proper emphasis on developing these technologies and to ensure that the goals of these programs remain consistent with DoD's overall S&T needs.

Table 1 Defense Critical Technologies

1	Semiconductor Materials & Microelectronic Circuits	The production and development of ultra-small integrated electronic devices for high-speed computers, sensitive receivers, automatic control, etc.
2	Software Engineering	The generation, maintenance, and enhancement of affordable and reliable software in a timely fashion.
3	High Performance Computing	High performance computing systems having 10^3 fold improvements in computation capability and 10^2 fold improvements in communication capability by 1996.
4	Machine Intelligence & Robotics	Incorporation of aspects of human "intelligence" into computational devices which enable intelligent function of mechanical devices.
5	Simulation & Modeling	Visualization of complex processes and the testing of concepts and designs without building physical replicas.
6	Photonics	Includes ultra-low-loss fibers and optical components such as switches, couplers, and multiplexers for communications, navigation, etc.
7	Sensitive Radar	Radar sensors capable of detecting low-observable targets, or capable of non-cooperative target classification, recognition, and/or identification.
8	Passive Sensors	Sensors not needing to emit signals to detect targets, monitor the environment, or determine the status or condition of equipment.
9	Signal & Image Processing	Combination of computer architecture, algorithms, and microelectronic signal processing devices for near real-time automation of detection, classification, and tracking of targets.
10	Signature Control	The ability to control the target signature (radar, acoustic, optical, or other) and thereby enhance the survivability of vehicles and weapon systems.
11	Weapon System Environment	A detailed understanding of the natural environment (both data and models) and its influence on weapons system design and performance.
12	Data Fusion	The machine integration and/or interpretation of data and its presentation in convenient form to the human operator.
13	Computational Fluid Dynamics	The modeling of complex fluid flow to make dependable predictions by computing, thus saving time and money previously required for expensive facilities and experiments.
14	Air Breathing Propulsion	Light-weight, fuel efficient engines using atmospheric oxygen to support combustion.
15	Pulsed Power	The generation of repetitive, short-duration, high-peak power pulses with relatively light-weight, low-volume devices for weapons and sensors.
16	Hypervelocity Projectiles & Propulsion	The ability to propel projectiles to greater-than conventional velocities (over 2.0 km/sec), as well as understanding the behavior of projectiles and targets at such velocities.
17	High Energy Density Materials	Compositions of high-energy ingredients used as explosives, propellants, or pyrotechnics.
18	Composite Materials	Two or more constituent materials that are combined together in such a manner to produce a substance possessing selected properties superior to those of its individual components.
19	Superconductivity	Makes use of the zero resistance property and other unique and remarkable properties of superconductors for creation of high-performance sensors, electronic devices and subsystems, and supermagnet based systems.
20	Biotechnology	The systematic application of biology for an end use in military engineering or medicine.
21	Flexible Manufacturing	The integration of production process elements aimed at efficient, low cost operation for small, as well as high, volume part number variations, with rapidly changing requirements for end product attributes.

Table 2.A. Funding for Critical Technologies (With SDIO)
(Millions Then Year Dollars)

Technology	FY 1987-91 ACTUAL	FY 1991 REQ	FY 1991 ACT	FY 1992 REQ	FY 1993 REQ	FY 1994 REQ	FY 1995 REQ	FY 1996 REQ	FY 1997 REQ
1 Semiconductor Materials & Microelectronic Circuits	1,955	370	534	479	481	487	488	490	510
2 Software Engineering	384	115	133	149	148	153	155	156	157
3 High Performance Computing	414	80	108	172	219	273	301	349	350
4 Machine Intelligence & Robotics	551	116	182	146	142	145	144	144	143
5 Simulation & Modeling	1,230	202	300	334	343	340	335	344	344
6 Photonics	710	75	167	186	190	180	179	190	173
7 Sensitive Radars	669	110	169	196	201	192	188	191	192
8 Passive Sensors	2,065	460	428	530	554	523	512	514	509
9 Signal & Image Processing	753	130	221	235	230	232	234	240	219
10 Signature Control	* 572	*120	*120	*109	*102	*89	*87	*86	*88
11 Weapon System Environment	929	180	213	232	238	246	249	252	260
12 Data Fusion	288	50	96	106	109	108	98	98	93
13 Computational Fluid Dynamics	428	55	118	94	95	99	101	105	108
14 Air Breathing Propulsion	968	180	227	224	211	185	190	193	201
15 Pulsed Power	541	95	95	76	76	81	80	80	82
16 Hypervelocity Projectiles & Propulsion	710	120	153	183	205	201	200	197	196
17 High Energy Density Materials	409	76	82	84	86	95	93	96	98
18 Composite Materials	1,089	170	204	193	197	211	218	224	229
19 Superconductivity	345	88	58	66	51	54	54	55	57
20 Biotechnology	79	100	69	65	66	68	69	71	72
21 Flexible Manufacturing	105	17	27	25	28	29	31	32	31
Planned Total Funding for Defense Critical Technologies - S&T with SDIO	15194**	2909**	3884**	3874**	3972**	3991**	4006**	4107**	4112**
Projected Total Funding for all Technology Development Activities - S&T with SDIO	NA	9784	9048	11095	11413	11749	11501	10895	10542

Table 2.B. Funding for Critical Technologies (Without SDIO)
(Millions Then Year Dollars)

Technology	FY 1987-91 ACTUAL	FY 1991 REQ	FY 1991 ACT	FY 1992 REQ	FY 1993 REQ	FY 1994 REQ	FY 1995 REQ	FY 1996 REQ	FY 1997 REQ
Planned Total Funding for Defense Critical Technologies - S&T without SDIO	10944**	1989**	3081**	3144**	3179**	3200**	3211**	3308**	3309**
Projected Total Funding for all Technology Development Activities - S&T without SDIO	NA	5324	6186	6015	6223	6339	6489	6770	6886

* Funding for this Critical Technology are unclassified totals only.

**Totals do not include funding for classified Signature Control efforts.

ACT - Actual Budget

REQ - Budget Request

Based on this ongoing appraisal, DoD may introduce fact-of-life changes into the FY 1993 budget and will provide guidance for the development of the FY1994-1999 FYDP. While recognizing the need for continuity, DoD will modify the milestones and the budgetary priorities for individual Defense Critical Technologies to reflect promising new technology developments and emerging military needs.

This plan consists of five chapters and two appendices. Chapter II discusses how the emerging security environment affects DoD's future military needs, describes how DoD's defense technology strategy is responsive to these future needs, provides an overview of the 21 Defense Critical Technologies, and describes key attributes of these technologies. Chapter III contains brief summaries of each of the 21 Defense Critical Technologies, and Chapter IV describes DoD's funding support for these technologies. Chapter V describes the overall DoD Science and Technology management process. Annex A provides detailed S&T funding summaries by fiscal year for each of the 21 Defense Critical Technologies. Annex B includes a description of the selection methodology and detailed technology plans for the 21 Defense Critical Technologies, including technology milestones and objectives, government and private sector R&D activities, industrial base profiles, and international assessments.

II. TECHNOLOGY INVESTMENT PLANNING

Emerging Security Environment Challenges to DoD

In a major address on national security at the Aspen Institute in August 1990, President Bush underscored the importance of defense R&D: "To cope with the full range of challenges we may confront, we must focus on readiness and rapid response. And to prepare to meet the challenges we may face in the future, we must focus on research — an active and inventive program of defense R&D."

Based on this mandate and in concert with global political events and military trends, DoD developed the Critical Technologies Plan provided here.

The following threats still challenge us:

- a) The dissolution of the Warsaw Pact as a military organization is changing the U.S. national security problem; but the Soviet Union continues to be a potential threat to the U.S. While our national defense strategy no longer focuses primarily on Europe and the possibility of Soviet aggression there, we must not discount that nation as a formidable military force.
- b) Second, we must deal with the rapid diffusion of advanced weapon technologies to regional powers, including potentially unpredictable and ruthless regimes.
- c) Growing, too, is the potential for smaller conflicts, ranging from violence spawned by narcotics trafficking, to terrorism, and to insurgencies.

In tandem with this emerging security environment, the United States is likely to face new resource constraints. DoD plans a 25 percent reduction in active forces in the next five years, and procurement outlays are programmed to fall from \$79.1 billion in FY 1991 to \$71 billion in FY 1996.

All of these factors point to the importance of a strong and stable research and development posture that is tied directly to our defense strategy, funded appropriately, and managed effectively.

DoD Science and Technology Strategy — Responding to the Challenges

Our strategic vision for defense technology takes a twenty-year view as it looks at three streams of technology:

1) Putting in place a process that provides orderly, evolutionary improvements in weapon systems, their subsystems, and support systems, such as the training, logistics, and defense industrial base infrastructure. These improvements must be responsive to future security threats and environments. The Services are the primary agents for these evolutionary technology changes.

2) Generating innovative, highly leveraged breakthrough technology and inserting this technology efficiently into our military capability. Here the Defense Advanced Research Projects Agency (DARPA) plays a major role, as does the Strategic Defense Initiative (SDI) program, the Balanced Technology Initiative, and the Services.

3) Seeking technology trump cards (to be played every 5 to 10 years) to sustain long-term dominance in the technological arms race. Recent examples of such trump cards

are stealth aircraft; older examples include the atomic bomb and the Polaris system. Trump cards bring about major shifts in how we think about and conduct war. Steady generation of such trump cards will assure long term dominance in defense technology for this country.

We need all three — evolutionary improvements, breakthrough technologies, and trump cards; and we need to manage defense S&T to allow for the development and application of all three. To do so, our strategy focuses on several themes:

- 1) Modularity in design and construction of platforms. We do not expect many new starts of major weapon platforms in the next ten to twenty years. Therefore, we plan on enhancing the capability and longevity of those systems by designing them with modular improvements in mind.
- 2) A systematic program to upgrade key subsystems of existing weapon systems (e.g., avionics, propulsion plants, weapons, communications, and countermeasures) as threats evolve. The wealth of technological opportunities will be exploited for potential applications to provide superior weapon performance and affordability.
- 3) A stronger focus on our S&T (6.1, 6.2, and 6.3a) programs to provide the technology push for future capabilities, and supported by a restructured and modernized in-house Research, Development, Test, and Evaluation (RDT&E) establishment.
- 4) Producing quality products at an affordable cost by keeping the mainstream of system and subsystem developments evolutionary, while preserving opportunities for revolutionary, high-leverage, timely improvements.
- 5) A stronger combination of innovation in technology and in operational concepts by identifying and demonstrating the opportunities for highly leveraged technology insertions and their interaction with operational innovations.
- 6) Radical acceleration of the development, introduction, and use of flexible manufacturing technology and training technology.
- 7) Stronger emphasis on an integrated approach to engineering analysis, modeling and simulation, gaming, prototyping, development, test and evaluation, and net technical assessment.
- 8) Forecasted mission needs should influence, in large measure, particular program or technology development efforts.

One of the primary tools by which we will manage the implementation of this technology strategy is the Defense Critical Technologies Plan. Each technology identified this year was selected based on its individual merits. We analyzed how each technology would contribute to improving military capabilities for a wide range of scenarios of military conflict, and we selected technologies and the technical objectives for them on the basis of maximum payoff. The process is described more fully in Annex B. Collectively, these technologies reflect, one aspect of DoD's long-term, consistent approach to S&T.

In 1990, DoD modified several of the technologies (which are reflected in minor title changes). These changes more accurately describe recent technological developments and DoD's current areas of emphasis within these broad technology areas. DoD also added a new technology, flexible manufacturing (not to be confused with the long-standing Manufacturing Technology (ManTech) Program), to acknowledge the increased importance of maintaining technological superiority in advanced manufacturing process technologies.

The Defense Critical Technologies Plan gives us a means to identify and describe these technologies and to develop and apply them to those military systems and subsystems that will give us the highest leverage.

To do this we have taken the list of 21 technologies and placed them in five clusters (see Figure 1). The clusters are a manageable way of looking at the vast array of opportunities available to us. They are a plausible way of organizing for action, a convenient way to illustrate broad themes. Our clusters also demonstrate the high degree of interdependence among these technologies in spite of their diversity. The clusters and their associated technologies are not unique, but they are useful in providing broad objectives.

Figure 1 Defense Critical Technologies Clusters

Critical Technologies	Computing/ Information	Sensing	Materials & Manufacturing	Energy & Material Flow Management	Infra- structure
1 Semiconductor Materials & Microelectronic Circuits	•	•	•		
2 Software Engineering	•		•	•	•
3 High Performance Computing	•	•	•	•	•
4 Machine Intelligence & Robotics	•		•	•	•
5 Simulation & Modeling	•			•	•
6 Photonics	•	•			
7 Sensitive Radars	•	•			
8 Passive Sensors		•	•		
9 Signal & Image Processing	•	•			
10 Signature Control		•	•		
11 Weapon System Environment		•			•
12 Data Fusion	•				
13 Computational Fluid Dynamics	•		•	•	
14 Air Breathing Propulsion			•	•	
15 Pulsed Power			•	•	
16 Hypervelocity Projectiles & Propulsion	•		•	•	
17 High Energy Density Materials			•	•	
18 Composite Materials			•	•	
19 Superconductivity		•	•	•	
20 Biotechnology			•		
21 Flexible Manufacturing			•		•

- The first two clusters are computing/information and sensing. These embrace technologies that primarily involve the processing, acquisition, manipulation, synthesis, transmission, simulation and denial of information. They form the core of advanced C³I, electronic warfare, target acquisition, and guidance. The strong information emphasis in the Defense Critical Technologies corresponds to the growing importance of information in both deterrence and modern combat. The ability of the United States to acquire and effectively use information, while denying accurate information to adversaries, can help compensate for planned reductions in U.S. force structure and forward deployed assets. Moreover, the development of “brilliant” stand-off weapons and other systems with advanced automatic target recognition capabilities — innovations that are highly dependent upon continued progress in the information and sensing areas — also will become important force multipliers that greatly enhance U.S. capabilities to project military power in the coming decades.
- Materials and manufacturing processes are critical to DoD’s ability to translate advanced technologies into high quality, reliable, and affordable equipment. Regardless of their potential in the laboratory, advanced defense technologies cannot enhance military capabilities unless they are rapidly and efficiently incorporated into fielded systems. Innovative process technologies are a key to helping reverse long-term acquisition trends toward escalating unit costs, lengthening lead times, and increasing difficulties in the incorporation of technological advances into operational systems. These trends, if not addressed, have serious implications for the ability of DoD to sustain its planned force structure in an era of constrained procurement budgets, as well as DoD’s ability to rapidly field new systems to counter unanticipated technological vulnerabilities.

The addition of flexible manufacturing to the 1991 list of Defense Critical Technologies — the only such change this year — reflects DoD’s growing appreciation of the importance of process technology in the acquisition and support of advanced weapon systems. Sophisticated flexible design and production techniques can help in reducing costs, compressing development cycles, and improving the quality and reliability of advanced military equipment.

The other technologies in the materials and manufacturing processes cluster also have a strong process orientation and, as a group, can have an important impact on improving system acquisition. For example, in software — which accounts for approximately 10 percent of DoD’s procurement and O&M budget — innovations in the generation of reliable and maintainable software code for sophisticated applications would yield dramatic procurement savings, eliminate a major source of program delays, and greatly enhance the reliability of U.S. weapon systems.

- In comparison with the other clusters, the energy and material flow management area includes more system-specific technologies that

are vital to upgrading the performance of existing weapon systems, as well as less mature technological areas that have the strong potential to provide "breakthrough" capabilities that are important to sustaining U.S. technological preeminence into the next century. For example, the development of advanced aircraft turbine engines, air-breathing propulsion, more lethal munitions, and high energy density materials are integral components in DoD's growing emphasis on enhancing military capabilities through subsystem upgrades that incorporate advanced technology. On the other hand, pulsed power, hypervelocity projectiles, and superconductivity could lead to radically new weapons or order-of-magnitude improvements in the capabilities of existing systems.

- Fifth is the broad area of technical infrastructure related to the vast efforts of DoD to employ the best technology and equipment for training, logistics, and control. It includes such technologies as simulation and modeling, information systems, and training systems.

In summary, the Defense Critical Technologies broadly support DoD's future needs for enhanced capabilities for acquiring, manipulating, and effectively using information; for the development of more efficient process and product technologies to improve system acquisition; and for technologies that contribute to both continual, evolutionary improvements in the capabilities of major weapon systems, as well as lay the groundwork for breakthrough innovations to ensure U.S. technological superiority in the coming decades.

Defense Technology Program Objectives

The general objectives are unchanged from last year and are summarized as follows:

Primary:

- To provide the major advances that will permit the timely design, manufacture, and fielding of advanced weapon systems and subsystems, as well as supporting systems for all parts of the military forces.

Secondary:

- To select and train future leaders and experts in defense-critical advanced technology areas; to make them available for downstream R&D programs;
- To transfer the appropriate technologies to private industry in order to increase international competitiveness.

Supporting objectives:

- Effective management of resources (skills, facilities, budgets);
- Protection of scientific and technological achievements from transfer to unauthorized parties;
- Appropriate, effective, and timely communications within the Department, and with the Congress, the scientific community, and industry;

For each of the critical technologies, specific technical objectives for the next ten to twenty years have been established, with inputs from the Services and the Defense Agencies

and the help of the Defense Science Board and the Service laboratories. Defense industry associations also provided their inputs. These are described in Chapter 3 and Annex A.

Critical Technologies Attributes

Taken as a whole, the Defense Critical Technologies have several key attributes that are significant for DoD S&T management, including:

- Criticality;
- Continuity;
- Interdependence; and
- Dual-use.

Criticality. The technical achievements planned for the Critical Technologies are essential for the fielding of superior quality forces in the future.

Continuity. Except for the addition of flexible manufacturing, this year's list of Defense Critical Technologies is identical to that published in 1990 and has changed little since the list was first released in 1989. Meanwhile, some technical objectives have been changed as the result of reported accomplishments and evolving military needs.

Interdependence. In general, progress in any single Defense Critical Technology depends in part on parallel advances in a variety of other important technologies. For example, advanced microelectronic circuits are central to the development of sophisticated computer architectures. In turn, improvements in computing capabilities are a prerequisite to desired innovations in simulation and modeling, computational fluid dynamics, signal processing, data fusion, machine intelligence, flexible manufacturing, and other important fields, including (to complete the circle) semiconductor electronics. This high degree of technological interdependence requires a balanced approach to technology development. Devoting an excessive amount of R&D resources to any single technology or small group of specific technologies is unlikely to achieve the desired results if such unbalanced efforts retard the development of supporting technologies.

While the Defense Critical Technologies are highly interdependent, as a group they are also extremely diverse. Microelectronic circuits, signature control, biotechnology materials, and high energy density materials incorporate a broad range of scientific disciplines and correspond to a wide set of future military needs. Moreover, advances in any specific Defense Critical Technology require a broad-based, interdisciplinary R&D approach. For example, unlocking the revolutionary potential of superconductivity requires the integration of expertise from fields such as materials science, physics, computer science, and chemistry. The breadth of the technologies and the diverse expertise required to achieve advances in any specific technology illustrate the importance of a broad S&T base as a critical foundation in the development of advanced weapon systems.

Dual-use. Finally, the Defense Critical Technologies shows that modern military power is largely dependent upon dual-use technologies. At least 15 of the 21 Defense Critical Technologies, in addition to contributing to vital DoD missions, have significant commercial applications or potential. For example, advances in semiconductor materials and microelectronic circuits, software engineering, and biotechnology will yield substantial benefits to both DoD and the civilian economy. In contrast, only six of the DoD Critical Technologies, sensitive radars, signature control, weapon system environment, pulsed power, hypervelocity projectiles and propulsion, and high energy density materials are largely militarily unique.

The importance of dual-use technologies is further illustrated by the extensive overlap among the Defense Critical Technologies and comparable collections of commercially oriented technologies. Except for the six military-specific technologies, all of the Defense Critical Technologies correspond closely to one or more of the technologies highlighted in the Department of Commerce's 1989 list of emerging technologies as well as the March 1991 list of National Critical Technologies compiled by an advisory panel sponsored by the Office of Science and Technology Policy. Moreover, this convergence of military and commercial technology is likely to become more pronounced as advanced weapon systems become increasingly dependent upon information technologies, which are also vital to a broad range of commercial and industrial applications.

III. SUMMARY OF DEFENSE CRITICAL TECHNOLOGIES PLANS

This chapter provides brief summaries of the detailed technology plans for each of the 21 Defense Critical Technologies. These summaries include a concise description of the technology area, its application to future military systems, illustrative technology objectives and milestones, and the potential impact of the technology on the defense industrial base. Detailed information on these and related issues for each of the Defense Critical Technologies may be found in the comprehensive technology plans provided in Annex B.

1. *Semiconductor Materials and Microelectronic Circuits* encompasses the production and development of ultra-small integrated electronic devices for high-speed computers, sensitive receivers, automatic control, etc. The principal component fields of this critical technology are:

- Very large scale integrated circuits
- CAD for complex circuits
- High resolution lithography
- Analog/digital converters
- Power converters
- Micro- and millimeter wave sources and amplifiers
- Transmit/receive modules and arrays
- Signal control components
- Radiation hard isolation technology

The information processing capability provided by advanced microelectronic devices is truly pervasive in U.S. weapon systems, and is likely to become even more so. The availability of microcircuit technology continues to have two major effects on the development of new systems. First, the technology makes it possible to extend the flight control envelope of aerodynamically unstable aircraft, and second the technology allows the creation of radically new systems, like smart weapons. The systems made possible by this technology provide a qualitative advantage to U.S. forces by increasing the soldier's ability to acquire and act upon information and to deliver weapons against the adversary. "Ultra-small" circuits have allowed a shrinking of the volume of computational capability required by smart weapons. As these devices have become smaller, the manufacturing technology required to fabricate them becomes more highly specialized and requires continued research and development into processes, equipment, and materials. Much of the R&D thrust towards higher levels of miniaturization and increased performance is applicable to both the defense and commercial sectors; however, battlefield requirements for ruggedness, radiation-hardness, and extreme environments are unique to defense systems. Research in microelectronic circuits is aimed at achieving several major objectives for weapon systems. Central to DoD requirements is a need to perform signal processing at gigahertz speed levels and beyond. This will require components of advanced materials whose feature sizes are below one-quarter micron. In addition, DoD is developing ever-increasing levels of integration with the objective of wafer-scale integration of logic and memory to further reduce system size and cost. Detailed plans for the development of this critical technology are in Annex B, on page 1-1.

2. *Software Engineering* refers to the generation, maintenance, and enhancement of affordable and reliable software in a timely fashion. The principal component fields of this critical technology are:

- Software and system engineering processes and environments
- Real-time/fault-tolerant software
- Reuse and re-engineering
- Software for parallel and distributed heterogeneous systems
- High assurance software

The "smarts" of major defense systems, including weapon systems, information systems, and scientific/engineering systems, are usually embodied in software. Indeed, software capability has become a principal determiner of overall weapon systems capability. In theory, software has enormous potential power and flexibility. In practice, software development and management is a complex, labor-intensive process, and our software capability is bounded by the extent to which the complexities in this process can be managed through attention to process and use of tools. Automated tools, linked together in software and system engineering environments that coordinate and manage tool operation, can take over many of the details of software engineering activity, yielding more cost-effective processes and potentially larger and more powerful systems. By 1993, DoD will be making experimental use of software engineering environment frameworks supporting use of commercially compatible tools to manage large scale software development. Design of embedded defense software usually involves management of "real-time" constraints and deadlines for processing of incoming sensor data and generation of outgoing control signals. In the presence of unreliable system components, the software must be designed in a fault-tolerant manner. By 1995, DoD will be demonstrating distributed operating systems supporting time-constraints and fault-tolerance. Much of the DoD software expenditure is in post-deployment activity or software logistics. Technology to facilitate management and re-engineering of existing assets can not only reduce post-deployment costs, but also greatly facilitate creation of reusable software assets such as simulation. The principal opportunity in reuse is megaprogramming, which is the development and management of DoD software applications on a component-by-component basis rather than instruction-by-instruction. Megaprogramming technology includes software component definition and composability technology, software tools and environments supporting component composition, software component libraries, associated capabilities for software electronic commerce, and software process models supporting reuse. By 1998, DoD will demonstrate the ability to develop domain-specific systems architectures and reusable components compliant with these specifications. High performance computing systems of all kinds, including scientific/engineering systems, embedded systems, and the leading edge information systems, employ parallel and distributed processing. By 1994, DoD will demonstrate systems software for survivable distributed and parallel computing. High assurance software technology is required in the design of safety-critical systems, including most weapon systems, and secure systems, in which confidentiality and integrity must be assured to a high level of confidence. By the mid-1990s, DoD will demonstrate highly secure and reliable operating systems, database management systems, and other related components. In each of these software technology areas, DoD must work to stimulate commercial development of off-the-shelf products that can be made to meet military needs. Detailed plans for the development of this critical technology are in Annex B, on page 2-1.

3. *High Performance Computing* – Rapid improvements in the performance and cost effectiveness of computer hardware, enabled by integrated microelectronics technologies, have spread computing into all areas of military and civilian life. Performance is expected to exceed one trillion operations per second (teraops) by the mid 1990s as a result of the Presidential Initiative in High Performance Computing and Communications described in a supplement of the President's FY 1992 budget submission. Teraops computing systems will require billion bit per second (gigabit) networks. DoD is fully supporting this initiative in the DARPA HPC program. The major technology areas are:

- High performance computer systems
- Advanced software technology and algorithms
- High performance networking
- Basic research and human resources
- Defense specific technologies

These major technology areas can be characterized as follows: High performance computer systems developments are in four main areas: research for future generations of computing systems, system design tools, advanced prototype systems, and evaluation of early systems. Systems capable of sustaining 0.1 teraops for large problems will be available for deployment by late 1993 and the teraops systems will be available by 1996. Advanced software technology and algorithms will cover scalable libraries, programming languages, and analysis tools for scalable parallel systems in a workstation/server configuration. High performance networking technologies will be produced to satisfy the needs for gigabit networks. These involve interface, protocol, security and multiple types of service over a wide range of performance characteristics. Basic research and human resources will address long term national needs for more skilled personnel, enhancement of education, training, materials and curriculum development in the high performance computing science and engineering areas. Defense specific technologies will focus on special needs for embedded systems such as high density packaging, special accelerators, and realtime fault-tolerant systems.

These will provide a critical edge in performance for broad classes of weapons, command and control systems, and multilayer distributed battle management systems and simulations such as smart weapons with integrated C³I systems, platforms, or elements of Strategic Defense systems. This initiative will also contribute significantly to civilian applications such as climate ocean, semiconductor, superconductor, and combustion system modeling. Detailed plans for the development of this critical technology are in Annex B, on page 3-1.

4. *Machine Intelligence and Robotics* incorporates aspects of human intelligence into computational devices which enable intelligent function of mechanical devices. The principal component fields of this critical technology are:

- Image understanding
- Autonomous planning
- Navigation
- Speech and text processing
- "Machine" learning
- Knowledge representation and acquisition
- Adaptive manipulation and control

These systems will help human operators by functioning as decision-making aids. In the fast-paced battlefield of the future, intelligent machines will fuse, process, and analyze data, and present the results almost immediately. By processing huge amounts of data, machine intelligence can provide more effective tools for effective military intelligence, data analysis, battle management, timely decision-making, and survivability through distribution of tasking, machines, and data repositories. A pilot's associate is being developed which will provide an AI-based decision aid to significantly reduce the information load on military pilots by the turn of the century. In addition, machine intelligence and robotics applications will reduce the need for manpower while improving human response times. Robotics technology involves controlling complex mechanical devices under the direction of computer software in response either to fixed assumptions, or dynamically changing requirements. One example of this type of application is an autonomous robotic ground vehicle or an unmanned aerial vehicle. DoD will demonstrate artificial intelligence for autonomous weapons and vehicles by 2005. When combined with other rapidly advancing critical technologies, such as passive sensors or high performance computing, machine intelligence will provide automatic target recognition capabilities, allow truly effective diagnostic aids, and permit the development of robotic combat systems. First-generation machine intelligence systems already have proven their worth in both defense and commercial applications. Applications of robotics and intelligent machines in manufacturing environments will result in flexible manufacturing capabilities, with shortened setup and production lead times, greater industrial surge capabilities, enhanced quality, and reduced acquisition costs. Detailed plans for the development of this critical technology are in Annex B, on page 4-1.

5. *Simulation and Modeling*, computer-based, allows the visualization of complex processes and the testing of concepts and designs without building physical replicas. The principal component fields of this critical technology are:

- High-speed graphics
- Solution of non-linear equations
- Simulation verification and validation

Simulation and modeling technology has four major components: computers, networking, visualization, and software. DoD continues to develop advanced capabilities to simulate weapon systems and the tactics which most effectively utilize them as computer capabilities continually increase. This technology can be applied to every major DoD weapon development program to reduce design and production cost, shorten development lead-times, improve performance, improve command and control, and assist in training. By 2001, DoD will attain an order-of-magnitude cost reduction for training and human factors design. For example, training cost effectiveness can be increased by providing a realistic, interactive simulation involving tanks, aircraft, and ground personnel. The payoff for large-scale maneuver simulation, in terms of improved training at reduced cost, is enormous. For example, SIMNET provides a realistic interactive simulation of tanks, armored personnel carriers (APCs), fighter/attack aircraft, helicopters, and other systems. Additionally, in SIMNET newly proposed systems (such as vision devices, antitank weapons, and antihelicopter weapons) can be simulated digitally so that the utility of given technical and human-centered parameter requirements can be assessed before hardware is built. The use of simulation and modeling in the systems design process will enhance the operational suitability and effectiveness of virtually all human/machine systems, whether being initially procured or being modified. DoD is also pursuing battle management simulation technology to evaluate sophisticated systems in hostile environments. Efforts include development of environmental and terrain space technology (including artificial intelligence links to environmental information), environmental data characterization, and target recognition based on the environment. During FY 1992, the capability to rehearse carrier-based weapon system missions will be demonstrated. As the costs and complexity of hardware development increase, designers in all fields will begin to rely more heavily on modeling and simulation. Computer modeling has significantly affected R&D programs by providing researchers a stronger basis for weapon system design and effects (nuclear, conventional, and chemical) and understanding interactions among low-observables, materials, and geometries with electromagnetic radiation. Detailed plans for the development of this critical technology are in Annex B, on page 5-1.

6. *Photonics* is the use of light (photons) for the representation, manipulation, and transmission of information, and includes ultra-low-loss fibers and optical components such as switches, couplers, and multiplexers for communications, navigation, and other information processing applications. The principal component fields of this critical technology are:

- Laser devices
- Fiber optics
- Optical signal processing
- Integrated optics

Photonics technology has long been used in important niches in both defense and commercial applications. But it has been only recently that photonics technology developed the necessary tools and capabilities to bring about revolutionary new applications. By combining fast, massively parallel techniques with devices possessing high spatial resolution, photonics can provide order-of-magnitude improvements over today's conventional electronic devices. Defense photonics will provide currently unavailable capabilities through faster, smaller, more reliable, and more survivable systems. The small size, light weight, and resistance to electromagnetic interference of optical fibers provide major advantages in avionics, microwave, and communications systems, and will see deployment in the defense sector over the next decade. As an example, DoD will demonstrate optical signal processing at a rate of 500 million operations per second by 1996. Over the next 20 years, photonic signal processing devices increasingly will be incorporated into defense sensor, communication, and information processing systems. Photonic processing offers the promise of order-of-magnitude improvements in processing speed resulting from the natural parallel architecture and the high switching speeds of optical devices. By the turn of the century, DoD will demonstrate a 10 gigabit per second local area network. Integrated optics will enhance weapons capabilities in the areas of automatic target recognition, state-of-health monitoring, and detection avoidance. Photonics R & D will significantly affect the high-speed computing defense industrial base through the development of components such as high-speed lasers, detectors, sensors, interconnect media, and signal routing and control elements. Detailed plans for the development of this critical technology are in Annex B, on page 6-1.

7. *Sensitive Radar* refers to those radar sensors capable of detecting low-observable targets, or capable of non-cooperative target classification, recognition, and/or identification. The principal component fields of this critical technology are:

- Advanced monostatic radar
- Multistatic radar
- Radars for non-cooperative target recognition and aided/automatic target recognition
- Active phased array radar
- Laser radar
- Electronic counter countermeasures (ECCM)

Radars will continue as a primary sensor since they provide an all-weather capability and do not rely on threat emissions. Continued reduction in target observables will significantly reduce the effective range of existing U.S. surveillance, tracking, target classification, and weapon guidance systems. Sensitive radars (such as large power aperture monostatic radar, synthetic aperture radar, bistatic radar, wideband radar, laser radar, and advanced over-the-horizon (OTH) radar) will be required to handle future advanced low observable threats, and to provide needed ECCM capabilities. Advances in radar system components are needed to implement projected sensitive radar improvements. To achieve this goal, by FY 1993 DoD will demonstrate a 50-100 watt (peak), 10 GHz pulsed power transistor. Increasing radar sensitivity creates some significant technical challenges. First, increased sensitivity will require development of frequency generators with increased stability, systems with increased processing gain, and receivers and analog-to-digital converters with wider dynamic ranges. Second, increased sensitivity makes U.S. systems more vulnerable to enemy exploitation, interference by unwanted objects (e.g., birds), and natural phenomena. For phased array radars, DoD's objective is to apply advanced, solid-state distributed active processing and emitter technology, and antenna shapes conformal to mobile platforms. By FY 1992, DoD will demonstrate an 8-inch active array missile seeker which integrates guidance and fuse radar functions. DoD is developing laser radar systems for applications from target detection and tracking to navigation in order to exploit their inherent advantages, increased bandwidth, smaller size, higher resolution. To demonstrate this technology, DoD will prototype a laser radar for obstacle avoidance and target detection by 1996. Sensitive radar technology is a major factor in providing a technical edge to U.S. forces by enhancing detection, localization, classification, identification, and tracking capabilities. Conventional radars are a well-established commodity for military systems, while sensitive radar technologies are still in development and there is only a limited industrial base. Both the conventional and sensitive radar markets are primarily driven by DoD. Detailed plans for the development of this critical technology are in Annex B, on page 7-1.

8. *Passive Sensors* do not need to emit signals to detect targets, monitor the environment, or determine the status or condition of equipment. The principal component fields of this critical technology are:

- Passive seekers
- Advanced thermal imagers/IR focal plane arrays
- Infrared search and track sensors (IRST)
- Diffractive optics
- Sensors integration for target acquisition
- Advanced passive antennas
- Passive RF surveillance
- Passive acoustic surveillance
- Fiber optic sensors for environmental and systems status monitoring and navigation
- Superconducting sensors

Passive threat warning technology provides strategic or tactical alert so that defensive measures may be taken. These systems include radar warning receivers, laser warning devices, space-based electro-optic systems, and warning of passive electro-optic/infrared (EO/IR) guided missiles. The latter is particularly challenging and crucial to maintaining U.S. force survivability as heat-seeking missiles proliferate. Infrared search and track (IRST) sensors scan wide areas in order to detect and track air or ground targets. An airborne IRST for use against ship targets will be demonstrated in FY 1993. Advanced acoustic sensors are needed to counter the threat posed by rapid progress in submarine quieting. Multi-band passive electro-optical sensors can reduce the sensitivity of existing sensors to environmental and target signature variations. Integrated sensor approaches will allow for multiple functions and collection of multiple target signatures. Anti-radiation seekers will counter hostile radars and increase the survivability of U.S. forces by targeting enemy radars. A prototype advanced microscan receiver for detecting radiation sources will be constructed in FY 1992. Fiber optic sensors embedded in structures will provide continuous coverage of critical internal variables (like stress and temperature) to evaluate structural performance. The availability of low cost, high efficiency IR sensor technology would find wide application in *in-situ* process monitoring and control, such as real-time temperature monitoring and control of highly temperature-dependent materials refining applications and alloying processes; monitoring and control of temperatures during metal machining, sintering, and composite curing operations; and real-time analysis of chemical processes using time-of-flight laser spectroscopy. Detailed plans for the development of this critical technology are in Annex B, on page 8-1.

9. *Signal and Image Processing* technology is the combination of computer architecture, algorithms, and microelectronic signal processing devices for near real-time automation of detection, classification, and tracking of targets. The principal component fields of this critical technology are:

- Algorithm development
- Hybrid optical-digital techniques
- Control of phased arrays
- Artificial neural networks

Application of signal processing technology to weapon systems offers important advantages, such as reducing operator workload, improving system performance, and performing new functions, such as autonomous vehicle control. Perhaps the most immediate enhancements in signal processing and compression can be obtained through the use of new, very-high-performance algorithms, such as compactly-supported wavelet structures and the Gabor transform. Possibly the greatest challenge in signal processing technology is automatic target recognition (ATR), where DoD has a major program underway in algorithm development. The development of advanced ATR capabilities will result in both reduced operator workload and improved system performance. ATR algorithms have been developed for infrared search and track systems which scan for aircraft, and advanced algorithms using spatial temporal techniques will be demonstrated in FY 1992. In reconnaissance and imaging systems, advanced computer architectures will demonstrate new capabilities in the areas of image segmentation, feature detection/extraction, and pattern recognition of static objects. Here, the ability of neural networks to perform pattern recognition is being investigated for synthetic aperture radar, electronic warfare, and anti-submarine warfare. Phased arrays of sensors are electronically controlled through individual activation rather than mechanical steering, while the next technical advance is a conformal array, where the phased array is applied directly to the surface of the vehicle. The demonstration of an airborne conformal array using digital beam steering control will occur in FY 1994. The most important signal processing applications depend on advanced, high-speed, high-throughput processors. Acoustic array and anti-submarine warfare signal processing share a common technology base and were originally derived from marine seismic techniques for the petroleum industry. The further development of this technology has significant applications to both the military and commercial industrial base, such as the ability to recognize handwritten characters for data entry into computer systems. Detailed plans for the development of this critical technology are in Annex B, on page 9-1.

10. *Signature Control* is the ability to control the target signature (radar, acoustic, optical, or other) and thereby enhance the survivability of platforms and weapon systems. The principal component fields of this critical technology are:

- Radar signature (radar cross section) reduction
- Infrared, visual, and ultraviolet signature reduction and management
- Acoustic quieting
- Low probability of intercept radars, communications, and navigation (electronic emission control)
- Deceptive signature (emissions and decoys)
- Magnetic signature control
- Wake signature

The reduction or control of platform signatures greatly improves survivability, resulting in improved weapons effectiveness, while in some cases, the objective is signature enhancement for deception against hostile sensors. This technology area includes the reduction of the wakes created by moving any vehicle through water or air, and by emissions, such as rocket plumes. The reduction of radar signatures is accomplished by vehicle shaping, the use of radar absorbing materials to reduce radar echoes, and passive or active cancellation techniques. For infrared signatures, the reduction is brought about by cooling and/or heating the vehicle or its emissions and by applying special material for background matching to reduce detection by passive systems. In addition, there is a requirement to create low probability of intercept radars, communications, and navigation systems. These programs apply improved spectrum management capability, sensors, and navigation instruments to control sensor emissions to assure C3I and navigation, under low-observability operational constraints. Reduction of the signatures of weapon systems significantly affects their design, support, and effectiveness. Industrial process technologies which are critical to advanced signature control concepts include: computer-aided design and computer-aided manufacturing, computer numerically-controlled machine tools, laser and optical hardware, and robotics. New and improved manufacturing capabilities will be required to transfer new signature control technology materials to system applications that emphasize producibility, cost, and performance. Detailed plans for the development of this critical technology are in Annex B, on page 10-1.

11. *Weapon System Environment* incorporates a detailed understanding of the natural environment (both data and models) and its influence on weapon system design and performance. The principal component fields of this critical technology are:

- Ocean characterization and prediction
- Environmental characterization and prediction for path & target area conditions
- Target environment analysis and scene generation

Because of the increasing sensitivity of each generation of weapon system sensors, DoD systems, and strategic and tactical operations are increasingly influenced by natural environmental conditions (e.g., weather, seasons, terrain). The limitations and potential leverage of environmental factors must be clearly understood to increase existing system capabilities and performance, or to optimize the design of new systems. Weapon system environment technology is critical in the selection, development, and operation of superior weapon systems, for such missions as anti-submarine warfare (ASW), "smart" weapons, strategic defense, battlefield surveillance, and communications. For example, DoD will complete a data-driven model for Global Ocean Prediction by 1996. Current smart weapon systems performance degrades under certain environmental conditions. Integration of comprehensive environmental knowledge into the logic modules, design, and testing and evaluation of these systems will increase their effectiveness. DoD will develop integrated environmental simulator scene generation capability for tactical targeting and mission planning. Tactical weapons, as well as strategic defense, requires excellent understanding of the IR background as viewed from surface, air and space. Spinoffs from weapon system environment technology will provide a variety of benefits to the nation. Examples include marine and atmospheric weather prediction for disaster warning, optimal aircraft and ship routing, and the utilization of knowledge of the sea for predicting optimal fishing locations. Remote sensing of the environment will provide insights into crop optimization; improved remote detection and weather prediction capabilities will provide advanced warning of danger over land areas and at sea. Detailed plans for the development of this critical technology are in Annex B, on page 11-1.

12. *Data Fusion* incorporates machine integration and/or interpretation of data and its presentation in convenient form to the human operator. The principal component fields of this critical technology are:

- Theoretical foundations
- Algorithm and model development
- Data and knowledge base for fusion processing
- Development of reasoning systems

With the increasing speed and complexity of battle, DoD has recognized the need to integrate data obtained from disparate sensors to yield information about the location, movement, and types of targets. Data fusion technology includes data processing techniques for a wide range of military applications from sensor cueing to cockpit display integration to battle management. This technology will be part of military systems from simple weapons to large-scale information processing applications. As U.S. operational doctrine evolved to stress deep attack and interdiction capabilities, a concurrent demand was created for information describing the location, movements, and intentions of targets beyond the performance of conventional sensors. Programs will be initiated by DoD to meet this demand. To more fully meet the data needs of modern battle management, DoD will demonstrate at-sea fusion of land-based and ship-borne sensor data by 1995. The most complex aspect of fusion technology is dealing with uncertainties associated with data. The evolution of automated correlation and reasoning systems dealing with data and contextual information opens new possibilities for partitioning functions between human and machine, resulting in demonstration of multi-hypothesis reasoning in 1994. DoD research in data fusion will result in improvements to C3I systems by providing the basis for information processing and sensor management which is critical to surveillance activities, advanced "smart" weapon systems, and the design of advanced computer-supported command centers. High-speed, low-cost, reliable techniques for data fusion are of growing importance to automated manufacturing in the defense and non-defense sectors. Real-time process control, sensor-directed cells and workstations, and robot and effector manipulation are three examples of DoD data fusion initiatives aimed at manufacturing products faster and with higher quality. Detailed plans for the development of this critical technology are in Annex B, on page 12-1.

13. *Computational Fluid Dynamics* (CFD) is the modeling of complex fluid flow to make dependable predictions by computing, thus saving time and money previously required for expensive facilities and experiments. The principal component fields of this critical technology are:

- Computations of unsteady aerodynamic regimes
- Hypersonic flow solutions
- Turbulence modeling
- Internal flows
- Pre-processing (geometry and grid generation)
- Validation of CFD codes

Because the equations which govern fluid flow cannot be solved analytically, except for the simplest cases, computational techniques are used to solve the equations via numerical procedures on high-speed computers. Of interest to DoD is the ability of CFD to assist in the development of improved flight vehicles, ocean vehicles, air-breathing engines, and weapons including armor and anti-armor warhead design. This technology is a design tool, much like a wind tunnel, to increase the performance and effectiveness of aircraft, ships, missiles, and hypersonic vehicles. As an example, by 1994 DoD will demonstrate full 3-dimensional Navier-Stokes wing analysis, extending to unsteady aeroelastic analysis in 1996. CFD is essential to the design of hypersonic flight vehicles at speeds above Mach 8, where ground test facilities are limited. Additionally, CFD will be used to rapidly identify promising design concepts before wind tunnel tests are conducted, thus significantly reducing system development time. By 1996, the capability to model a complete submarine propulsor system will be demonstrated, assisting DoD in searching for the most effective design configuration. Overarching all of CFD technology is the problem of validation of the codes, recognizing that even the most complex codes are still only approximations. Massively parallel computing architectures and algorithms will produce a huge increase in CFD capabilities over current supercomputers. CFD has proved to be a powerful tool for the U.S. aerospace industry for design modification and problem solving in both military and commercial programs. Its use in the design of next-generation aircraft is expected to help ensure the international competitiveness of the domestic industrial base. Detailed plans for the development of this critical technology are in Annex B, on page 13-1.

14. *Air-breathing Propulsion* represents the development of light-weight, fuel efficient engines using atmospheric oxygen to support combustion. The principal component fields of this critical technology are:

- High pressure ratio, lightweight compression systems
- High-temperature, improved life combustion systems
- High-efficiency, highly loaded turbines
- Reduced signature, multi-functional nozzles
- Adaptive, survivable, high-speed integrated control systems
- High-speed, high-temperature mechanical systems
- Operationally realistic, environmentally valid technology demonstrations
- Scramjet combined cycle technology development/demonstration
- Advanced fuels/systems for hypersonic applications

Since their introduction in the 1940s, gas-turbine engines have rapidly evolved, resulting in substantial improvements to performance, fuel economy, and reliability. Turbine engine performance improvements provide the keystone to continued superiority in all DoD aircraft and cruise missile programs, as both upgrades to existing platforms and power sources for new platforms. The Integrated High Performance Turbine Engine Technology (IHPTET) program is a three-phased effort aimed at doubling gas-turbine propulsion capability by the turn of the century. This program aims to advance the technology for turbofan engines (jet aircraft), turboshaft engines (helicopters), and expendable platforms (cruise missiles). Other air-breathing propulsion systems necessary for present and future programs include ramjet/supersonic combustion ramjet (scramjet), combined cycle, and diesel. It is probable that hypersonic propulsion ($> \text{Mach } 5$) will use an air-breathing system, such as a scramjet engine. This high-speed regime poses a new and different series of problems in aerodynamics, engine design, and propulsion/airframe integration. In order to advance propulsion technology, R&D will be required into new materials, reduced signatures, and survivable control systems. These technology developments are leading to "smart engines", which will be capable of actively monitoring and reacting to internal engine conditions to maximize overall performance. Aircraft gas-turbine technology provides militarily superior engines with applications for military and commercial engines, and thus supports domestic competitiveness for the civilian aircraft industry. Advances in materials, design, and aerothermodynamic techniques can be expected to contribute significantly to a wide spectrum of the military and commercial industrial base and continue U.S. preeminence in the air-breathing propulsion technology base. Detailed plans for the development of this critical technology are in Annex B, on page 14-1.

15. **Pulsed Power** technology is the generation of repetitive, short-duration, high-peak power pulses with relatively light-weight, low-volume devices for weapons and sensors. The technology encompasses techniques for conversion, storage, pulse-forming, and transmission of electrical energy. The principal component fields of this critical technology are:

- Energy storage
- Power switching
- Conditioning circuits
- Power sources
- High power microwave

Pulsed power technology is required for directed energy weapons (DEW), kinetic energy weapons (KEW), and ground- and space-based identification and surveillance systems. Weapon systems like KEW use hypervelocity projectiles for long-range engagements, and rapid firing rates for anti-missile and anti-armor defense. In addition, pulsed power is also essential for other systems such as laser radars, ultra-wideband radars, and nuclear weapon effects simulators. Energy storage systems often consist of large, high-voltage, high-current capacitor banks that have a modular design. For military applications, energy storage systems must have high energy densities (kJ/Kg) to reduce system weight. In the near term (FY 1992), DoD will demonstrate energy densities to 10 kJ/kg from an inductive system, and in the longer term, DoD will demonstrate energy densities to 1MJ/kg by 1997, thus paving the way for high-performance directed energy weapons. This would also meet the requirements for the most advanced hypervelocity electro-magnetic guns, with velocities of >20 km/sec. Significant improvements are required in opening and closing switch technology for transferring the power from the pulse forming network to the various weapon system loads. This technology requires a high repetition rate using plasma, solid state, and magnetic elements. Detailed plans for the development of this critical technology are in Annex B, on page 15-1.

16. *Hypervelocity Projectiles and Propulsion* technology is the capability to propel projectiles to greater-than-conventional velocities (over 2.0 km/sec), as well as understanding the behavior of projectiles and targets at such velocities. The principal component fields of this critical technology are:

- Projectile design
- Projectile propulsion
- Projectile-target interaction

Hypervelocity projectiles provide more penetrating and destructive capability against armored targets, have an increased range, and a decreased time of flight. Applications are anti-armor systems (e.g., tanks, artillery), air defense systems, and theater or strategic missile or re-entry vehicle intercept (both endo- and exo-atmospheric) systems. Propulsion systems that are being investigated include electromagnetic (EM) guns (railguns and coilguns, electrothermal guns, traveling-charge guns with liquid or solid high-energy propellants, hypervelocity rockets, and explosively-driven shock tubes). New designs of armor-piercing, rod-shaped charges, explosively formed penetrators, and long-rod kinetic energy projectiles are also being developed. The X-Rod program is to explore the feasibility of an autonomous or command guided, high-speed kinetic energy penetrator against enemy tanks. DoD will test prototype projectile designs developed in this program in FY 1994. Developments such as reactive armor and complex multilayer armors will significantly reduce the effectiveness of the current antiarmor weapon inventory. The effective range of conventional unguided anti-aircraft projectiles is limited, because targets can maneuver out of the line of fire during the projectile's time-of-flight; however, a hypervelocity projectile's time-of-flight to the target is significantly reduced, thereby increasing the weapon's effective range. For space applications, the Exoatmospheric Thunderbolt effort includes development of a 56 mm EM gun, armature, and power system to achieve high velocity projectile launches, with testing of the prototype system planned for FY 1994. Major R&D efforts exist at the basic and applied research level; therefore, there is little manufacturing capability at this time. Industrial base issues arise from specialized material requirements and small, light, inertial guidance and measurement units. The industrial base is considered sparse because of the lack of maturity and limited size. The potential for commercial spin-off of EM gun technology is in the plating and welding area. Detailed plans for the development of this critical technology are in Annex B, on page 16-1.

17. *High Energy Density Materials (HEDM)* are compositions of high-energy ingredients used as explosives, propellants, or pyrotechnics. These compositions contain high-density stable explosive compounds, binders, plasticizers, and other energetic ingredients, such as metallic compounds. The principal component fields of this critical technology are:

- Explosive applications
- Propellant applications
- Warheads
- Chemically bound, excited state components
- Nuclear isomers

These materials may be able to release up to 10 times the energy now stored in current explosive materials and propellants. This is a field of high risk research and speculative payoff. HEDM propellants provide the means of getting most ordnance items to the target, and once near the target, provide the means to kill the target. The breadth of systems that will benefit from HEDM range from strategic missile propulsion, to mines, to conventional warheads, explosives and propellants. While increases in energy-density are continually sought, other important parameters include safety, stability, signature, toxicity, and reliability. One objective of the development program is advanced warhead design with higher lethality to compensate for increased miss distances, and to allow smaller warheads, more propellant, and longer ranges. For tank armor, a 50% increase in penetration thickness is sought, greatly increasing the vulnerable area of the enemy tank. A significant technology development effort is underway to reduce the signature of tactical missiles, reducing the danger of observation for the attacker. The goal is to develop a propellant with no visible signature and a factor of ten reduction in infrared signature. To meet these goals, DoD, DoE, and industry research programs must encompass scientific programs in combustion, detonation physics, reaction kinetics, and synthesis of new materials. The industrial base for HEDM provides its products to DoD, DoE, and NASA. Most non-military applications are related to satellite launch systems, NASA and commercial space customers, and commercial blasting agents. Detailed plans for the development of this critical technology are in Annex B, on page 17-1.

18. *Composite Materials* are defined as two or more constituent materials that are combined together in such a manner as to produce a substance possessing selected properties superior to those of its individual components. The principal component fields of this critical technology are:

- Polymer (organic) matrix composites
- Metal matrix composites
- Carbon matrix composites
- Ceramic matrix composites
- Hybrid composites

Composite materials possess high strength, low weight, and are able to withstand high temperatures for aerospace and other applications. Composite materials technology promises significant improvement for weapons performance, design, and affordability. For some systems, composites are recognized as the enabling technology required for fulfillment of demanding thermal, structural, and mechanical requirements (such as for the National Aero Space Plane (NASP), advanced gas turbines, deep submergence vehicles, spacecraft, ground combat vehicles, and long range cruise missiles). The major objectives for this technology are to: (1) develop alternative materials and manufacturing processes that provide composites and components with improved performance at acceptable cost to meet DoD mission requirements; (2) incorporate concurrent engineering, design, and producibility into materials and manufacturing processes; and (3) develop a focused mechanism for transitioning and supporting new composites rapidly into production applications. Metal matrix composites (MMCs) are an important emerging technology. DoD's development of MMCs will result in a demonstration of matrices for high thermal conductivity and high temperature applications by FY 1992. Composite materials will be needed to make future systems most effective in a wide spectrum of vehicle structures, including high-temperature propulsion systems, hypervelocity vehicles, short take-off and landing (STOL) and vertical take-off and landing (VTOL) vehicles, as well as for spacecraft, protection against directed energy threats, and advanced hull superstructures and forms and submarine structures. Composite materials offer the potential to provide lighter systems that are more agile and deployable than are possible with conventional approaches. By 2001, DoD will demonstrate a 25 to 50% weight reduction in airframes, land vehicles, and space vehicles. In addition, DoD is developing damage-tolerant composite materials and hardening concepts for protection of platforms and weapons systems against operational hazards and advanced threats. Military demand for high-performance materials in the United States is projected to maintain a thriving community of advanced materials and equipment suppliers. At present, advanced materials developed for military applications are expensive relative to the commercial sector. Detailed plans for the development of this critical technology are in Annex B, on page 18-1.

19. *Superconductivity* This technology makes use of the zero resistance property and other unique and remarkable properties of superconductors for creation of high-performance sensors, electronic devices and subsystems, and supermagnet based systems. The principal component fields of this critical technology are:

- Low temperature superconductors (LTS)
 - Supermagnets
 - Sensors and electronics
- High temperature superconductors (HTS)
 - Supermagnets
 - Sensors and electronics

Introduction of superconducting devices offers the potential for reducing drastically the energy losses and cooling requirements, which in turn make for much improved processing speed and packaging density in digital microcircuitry. The frequency selectivity in analog filters using superconductor elements can not be approximated by other types of devices. The recently discovered high-temperature superconducting materials offer further decreases in cooling requirements, promising the use of liquid nitrogen, rather than helium as a coolant, which makes potential applications much more practical. The challenge in the field is how to make the best possible (relatively near-term) use of the well established technology of low-temperature devices (operating at less than 23°K) while resolving the serious problems associated with the use of high-temperature superconductors, which in the long-term may be more promising.

The DoD LTS program covers electric drive system for ships, electric generators, magnetic energy storage systems, electromagnetic guns and catapults, microwave and millimeter wave generators, analog communication and surveillance system components, and digital electronic subsystems and systems, including analog-digital converters, cross-bar switch, cache-memories and digital signal processors. Many of these LTS developments will endure, but they will also serve as prototypes for later HTS applications which use transition temperatures as high as 125°K or possibly above. While the HTS devices impose lesser refrigeration penalties, problems of brittleness, crystalline anisotropy, corrosion and bulk current density still require extensive development. The DoD plan for HTS materials aims at the fundamentals in the development of bulk conductors for magnets, thin-film sensors and electronics, together with the associated manufacturing processes.

Superconductor applications will result in higher performance sensors and electronics for the military and reduced weight, volume and power requirements. Electromagnetic propulsion of ships and projectiles may become practical through the introduction of HTS devices. Detailed plans for the development of this critical technology are in Annex B, on page 19-1.

20. *Biotechnology* is the systematic application of biology for an end use in engineering or medicine with many potential defense applications. The principal component fields of this critical technology are:

- Processes
- Materials
- Sensors

Because of the discovery and exploitation of biological mechanisms that control living organisms, it is now possible to engineer microbial, plant, and animal cells to act as factories for the synthesis of existent or new materials at substantially enhanced rates and efficiencies. Biosynthesis of new enzymes, which are biological catalysts, offers the prospect of developing new pathways for synthesis or degradation of chemicals. The DoD is constantly pressing the forefront of materials technology, both because of the severe working environments and the need for extremely high reliability. Biotechnology may offer an attractive means for producing new classes of materials, at low cost, with the added strategic advantage of using non-petroleum-based feedstocks. The cost of developing some new materials is also likely to decrease when they are produced biologically because of the potential for producing "generic" materials that may be easily modified at the molecular level without the need to develop a new manufacturing scheme. Biosensors have extremely high selectivity and sensitivity, exceeding anything obtainable by non-biological sensors. The objective of the DoD sensor effort is to discover the basic principles used by living-system sensors and exploit them in designing new sensors. Advanced, antibody-based sensors for real-time detection of chemical and biological agents will be demonstrated in FY 1993. Bioprocesses have the intrinsic advantage of requiring far less energy and therefore can be considerably less costly. They are also less environmentally damaging and proceed with greater speed, specificity, and selectivity than do conventional processes. Additionally, recombinant DNA technology can be used to tailor organisms to perform specific tasks or to manufacture products that would be difficult or costly to obtain using conventional methods. Basic research efforts in decontamination technology are aimed at developing generic approaches to design of enzymes for catalytic degradation of broad classes of chemical warfare agents. There is a great need to be able to develop enzymes rapidly and inexpensively that will exhibit high activity for new chemical agents. FY 1995 is the target for meeting this goal. Testing of protective coatings and camouflage creams using existing enzymes is expected to be completed by FY 1993. This effort has been accelerated significantly during 1990 to meet the demands of the Persian Gulf War and a number of new materials will be produced in FY 1991. Detailed plans for the development of this critical technology are in Annex B, on page 20-1.

21. *Flexible Manufacturing* is the integration of production process elements aimed at efficient, low cost operation for small, as well as high volume part number variations, with rapidly changing requirement for end product attributes. Manufacturing involves people, equipment, materials, information, and controls acting together to transform materials into products. The principal component fields of this critical technology are:

- Product data definition for automated manufacturing
- CAD/CAM/CAE/CAPP
- Databases and database management
- Communications and networking
- Intelligent software interfaces

One of the key merits of flexible manufacturing is the ability to operate efficiently at variable production rates, to expand rapidly and efficiently to higher output levels, to accommodate reasonable changes in the output product specifications. Success hinges upon the reliable insertion of automated and flexible information (storage, processing, and retrieval) into the translation of design concepts, engineering, detailed designs, and the many diverse mechanical and other processes involved in manufacturing. The DoD technology development plan comprises standards for definition of product data, design of integrated computer aided design–engineering–manufacturing process planning and control, data management, and communications.

The impacts on DoD's future are seen as increased ability to accommodate, at affordable cost, the rapidly changing needs for prototyping, small production runs, and potential expansion to large–volume production. Changes in the manufacturing processes, caused by introduction of new design specifications or improved materials will be accommodated without expensive redesign of the whole manufacturing process. Industry will benefit from the standardization implied by the DoD program so that the diverse computer aided processes will be increasingly compatible and adaptable to integration at the single, and perhaps the multi–plant, levels. The need for upgrading personnel skills in order to achieve the best possible task distribution between human operators and production equipment will be addressed by both DoD and industry developmental activities. The training of semi–professionals in designing and operating highly automated systems will also benefit. Detailed plans for the development of this critical technology are in Annex B, on page 21–1.

IV. FUNDING OF DEFENSE CRITICAL TECHNOLOGIES

The development of advanced defense technologies requires predictable levels of investment and program support, but also the flexibility to make rapid adjustment when needed. DoD's investment strategy is thus designed to provide a strong, sustained approach to technology development. DoD's support for the Defense Critical Technologies reflects this consistent, long-term commitment.

Tables 2A and 2B in Chapter I provide a summary of estimated DoD funding for the Defense Critical Technologies in the FY 1987-91 period, as well as annual totals for FY 1992-97. These figures present funding from the DoD Science and Technology program and include the Strategic Defense Initiative Organization (SDIO), as well as a summary not including SDIO.

DoD research and technology efforts are managed as programs. In fundamental research, funds for specific technologies are generally readily identifiable. As research comes closer to application, the focus changes to programs that combine and integrate technologies to produce items of military utility. Cost accounting programs in DoD are geared to tracking program costs and are not well suited to tracing costs to technology areas. Further, military critical technologies by definition impact a wide range of applications. Details of the funding of Critical Technologies by program element are shown in Annex A.

DoD is planning for incremental, consistent, long-term increases in emphasis for S&T funding relative to other parts of the RDT&E program. Figure 2 shows that DoD S&T, and especially funding for critical technologies, fare well in light of the programmed reductions in Defense RDT&E (shown here without SDI funds). Projected S&T funding will grow from 16% of total DoD RDT&E in the President's FY 1991 request to more than 22% of RDT&E in FY 1997. During this same period, critical technologies funding increased from 8% to 12% of the total DoD RDT&E. It should be noted that these percentages are understated because classified funding is not included. This demonstrates the commitment we have made to keeping our S&T program strong.

Figure 3 illustrates that funding for critical technologies grows significantly as a fraction of S&T, whether or not SDI funds are a part of the picture. In particular, critical technology funds (excluding SDI) increase from approximately 37% to 52% of S&T. Of particular note is the emphasis on critical technology support over the last year as shown in the following table of budget requests and Congressional funding.

	FY 1991 Request	FY 1991 Congressional Funding	FY 1992 Request
Critical Technologies as % of S&T (without SDI)	37%	50%	52%
Critical Technologies as % of S&T (with SDI)	30%	41%	35%

Budget Requests and Congressional Funding Ratios

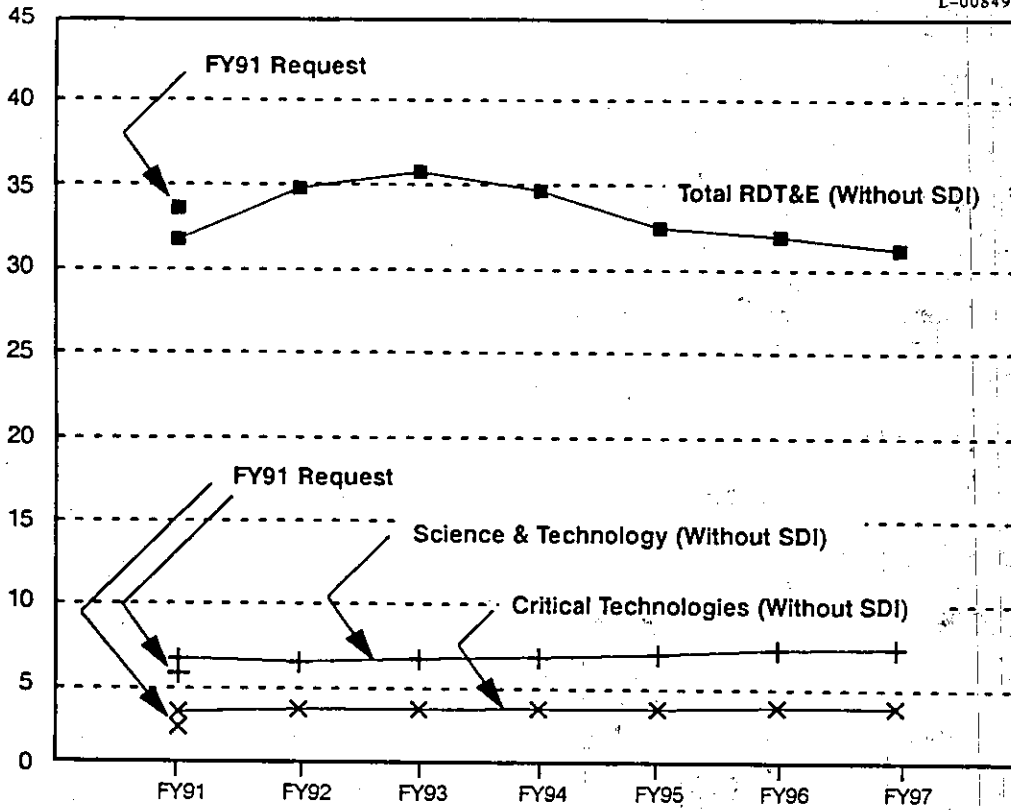


Figure 2 DoD RDT&E, Funding (\$ Billions)

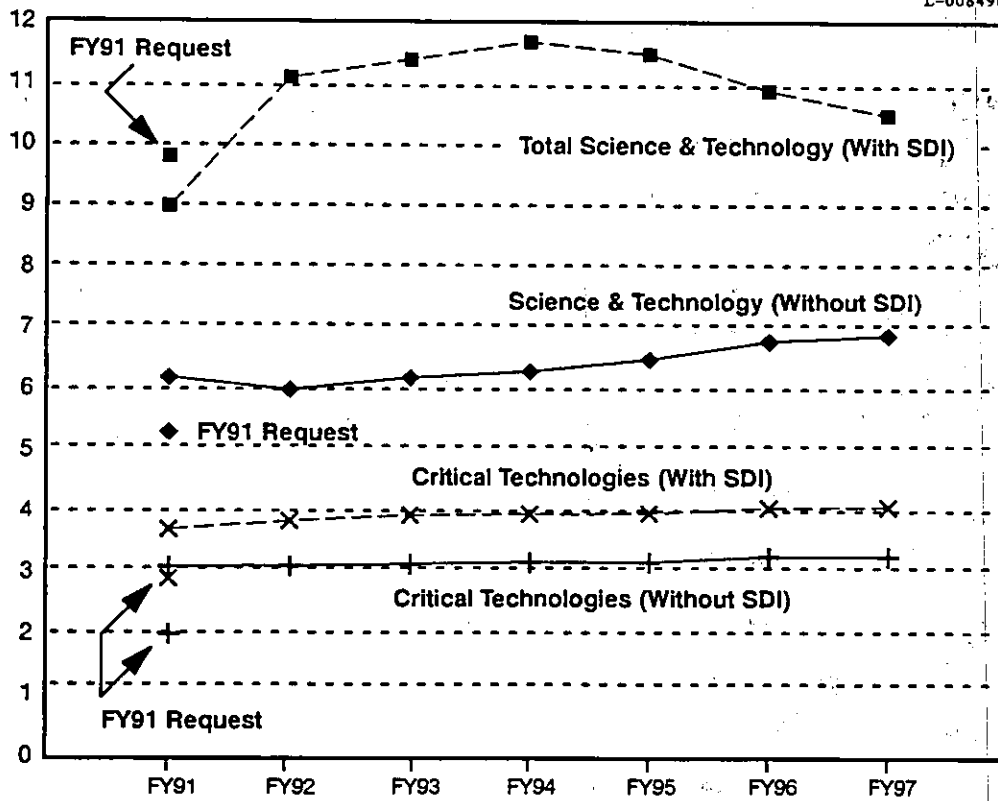


Figure 3 DoD Science & Technology Funding (\$ Billions)

For FY 1992, the resources for Service-executed evolutionary technology developments will be better managed because of the outcome of the Defense Management Review (DMR). Resources are also adequate for breakthrough, revolutionary technologies, with DARPA taking the lead and with contributions from the Services, the Department of Energy laboratories, and industry. Funding needs for trump card technologies are more difficult to characterize. Our goal in this arena must be to foster an environment that allows and rewards discovery and invention of those new basic science and engineering developments on which trump cards depend, while fostering high-level management sensitivity in DoD and the military for their importance and potential.

In line with the White House initiative on High Performance Computing and Communications, the Defense Critical Technologies Plan contains \$232 million for DARPA (as compared to the FY 1991 base of \$183 million) to pursue technical objectives associated with high performance computing, such as systems, network technology, and enabling software. This initiative, which is being coordinated by the Federal Coordinating Council for Science, Engineering, and Technology, is a balanced program to extend our nation's leadership in high performance computing and computer communications; to put those technologies to work for defense as well; and to make these technologies an integral part of science, technology, and industry. This is an example of the sort of high-leverage breakthrough opportunity we can capture with the right guidance and resources.

Our overall budget is sound, but we will reexamine opportunities and priorities for FY 1993 budget refinements and guidelines pertinent to the 1994-1999 FYDP. The full impact of our planning will be felt in FY 1994, as we continue to evaluate our priorities during the PPBS process and increase emphasis on higher priority programs, using the framework provided by the Defense Critical Technologies Plan and by further analysis of technical opportunities and new user needs.

V.

MANAGING SCIENCE AND TECHNOLOGY

The objectives of the DDR&E for the DoD S&T programs are:

1. To ensure a strong S&T program that uses to the full all available technical opportunities to meet the DoD users' needs;
2. To ensure that the S&T programs of the DoD are adequately resourced, with fully adequate resources devoted to the most important objectives, and with the lesser needs funded on an austere basis;
3. To ensure that the S&T programs are well managed by the performers, and that the technical output of the S&T programs are well utilized by the users.

The Defense Critical Technology Plan (DCTP) is an important management tool for achieving these objectives. In particular the DCT planning process will be used to provide a clear statement of the S&T program to the DoD Planning, Programming, and Budgeting System. This Statement will be made in terms of technical objectives, of improvements in military capabilities to be obtained from the use of the technical results, and of the resources required to achieve the technical results.

The technical program objectives and the desired improvements in military user capabilities will be set by the DDR&E, with the assistance of the Deputy DDR&E(R&AT), and the Defense Science and Technology Steering Group. The Services, Defense Agencies and others will make their contributions through the DS&T Steering Group.

The Defense Critical Technology planning process will provide continuous improvement for the S&T performers by involving military users and outside technical helpers as needed.

The DCTP and the DCT planning process will contribute importantly to the Acquisition process. They will do so primarily by providing a detailed but highly structured description of S&T program objectives. This will assist the DAB committees in evaluating the technical risk of DAB programs. Another contribution will come from the highly skilled cadre of technical experts, managers, and planners assembled by the DS&T Steering Group.