Department of Defense
Fiscal Year (FY) 2016 President's Budget Submission

February 2015

Defense Advanced Research Projects Agency

Defense Wide Justification Book Volume 1 of 1

Research, Development, Test & Evaluation, Defense-Wide

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Table of Volumes

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Department of Defense
FY 2016 President's Budget
Exhibit R-1 FY 2016 President's Budget
Total Obligational Authority
(Dollars in Thousands)

07 Jan 2015

Appropriation	FY 2014 (Base & OCO)	FY 2015 Base Enacted	FY 2015 OCO Enacted	FY 2015 Total Enacted	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Research, Development, Test & Eval, DW	2,752,656	2,870,932	45,000	2,915,932	2,972,693		2,972,693
Total Research, Development, Test & Evaluation	2,752,656	2,870,932	45,000	2,915,932	2,972,693		2,972,693

R-1C1: FY 2016 President's Budget (Published Version of PB Position), as of January 7, 2015 at 09:29:53

Department of Defense
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07 Jan 2015

Summary Recap of Budget Activities	FY 2014 (Base & OCO)	FY 2015 Base Enacted	FY 2015 OCO Enacted	FY 2015 Total Enacted	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Basic Research	341,350	392,903		392,903	389,663		389,663
Applied Research	1,133,007	1,102,303	45,000	1,147,303	1,209,380		1,209,380
Advanced Technology Development	1,126,615	1,304,364		1,304,364	1,302,079		1,302,079
Management Support	151,684	71,362		71,362	71,571		71,571
Total Research, Development, Test & Evaluation	2,752,656	2,870,932	45,000	2,915,932	2,972,693		2,972,693
Summary Recap of FYDP Programs							
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07 Jan 2015

Appropriation: 0400D Research, Development, Test & Eval, DW

Line No	Program Element Number	Item	Act	FY 2014 (Base & OCO)	FY 2015 Base Enacted	FY 2015 OCO Enacted	FY 2015 Total Enacted	FY 2016 Base	FY 2016 OCO	FY 2016 Total	Sec
2	0601101E	Defense Research Sciences	01	293,284	332,146		332,146	333,119		333,119	U
4	0601117E	Basic Operational Medical Research Science	01	48,066	60,757		60,757	56,544		56,544	U
	Basic Research			341,350	392,903		392,903	389,663		389,663	
9	0602115E	Biomedical Technology	02	121,152	114,790	45,000	159,790	114,262		114,262	U
12	0602303E	Information & Communications Technology	02	370,643	324,407		324,407	356,358		356,358	U
13	0602304E	Cognitive Computing Systems	02	15,847							U
14	0602383E	Biological Warfare Defense	02	25,648	43,780		43,780	29,265		29,265	U
18	0602702E	Tactical Technology	02	218,482	299,734		299,734	314,582		314,582	U
19	0602715E	Materials and Biological Technology	02	158,948	150,389		150,389	220,115		220,115	U
20	0602716E	Electronics Technology	02	222,287	169,203		169,203	174,798		174,798	U
	Applied Research			1,133,007	1,102,303	45,000	1,147,303	1,209,380		1,209,380	
38	0603286E	Advanced Aerospace Systems	03	146,789	129,723		129,723	185,043		185,043	U
39	0603287E	Space Programs and Technology	03	127,948	179,883		179,883	126,692		126,692	U
57	0603739E	Advanced Electronics Technologies	03	92,001	92,246		92,246	79,021		79,021	U
58	0603760E	Command, Control and Communications Systems	03	229,510	239,265		239,265	201,335		201,335	U
59	0603766E	Network-Centric Warfare Technology	03	261,613	360,426		360,426	452,861		452,861	U
60	0603767E	Sensor Technology	03	268,754	302,821		302,821	257,127		257,127	U
	Advanced Technology Development			1,126,615	1,304,364		1,304,364	1,302,079		1,302,079	
154	0605502E	Small Business Innovative Research	06	80,025							U

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163	0605898E	Management HQ - R&D	06	71,659	71,362		71,362	71,571		71,571	U
		Management Support		151,684	71,362		71,362	71,571		71,571	
Total Research, Development, Test & Eval, DW				2,752,656	2,870,932	45,000	2,915,932	2,972,693		2,972,693	

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19	0602715E	Materials and Biological Technology	02	158,948	150,389		150,389	220,115		220,115	U
20	0602716E	Electronics Technology	02	222,287	169,203		169,203	174,798		174,798	U
Applied Research				1,133,007	1,102,303	45,000	1,147,303	1,209,380		1,209,380	
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Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Budget Activity 02: Applied Research
Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Budget Activity 03: Advanced Technology Development (ATD)
Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Budget Activity 06: RDT&E Management Support
Appropriation 0400: Research, Development, Test & Evaluation, Defense-Wide

Program Element Table of Contents (Alphabetically by Program Element Title)

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Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency											Date: February 2015	
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*					R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*							
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
Total Program Element	-	293.284	332.146	333.119	-	333.119	328.362	339.350	343.736	355.434	-	-
BLS-01: *BIO/INFO/MICRO SCIENCES*	-	20.355	15.036	6.127	-	6.127	-	-	-	-	-	-
CCS-02: *MATH AND COMPUTER SCIENCES*	-	88.325	118.743	132.336	-	132.336	140.283	152.116	162.783	173.036	-	-
CYS-01: *CYBER SCIENCES*	-	23.720	58.462	53.774	-	53.774	45.000	47.219	27.000	10.000	-	-
ES-01: *ELECTRONIC SCIENCES*	-	35.969	37.411	40.401	-	40.401	44.578	36.951	39.796	44.883	-	-
MS-01: *MATERIALS SCIENCES*	-	93.010	73.077	70.368	-	70.368	69.966	72.233	73.780	85.138	-	-
TRS-01: *TRANSFORMATIVE SCIENCES*	-	31.905	29.417	30.113	-	30.113	28.535	30.831	40.377	42.377	-	-

A. Mission Description and Budget Item Justification

The Defense Research Sciences Program Element is budgeted in the Basic Research Budget Activity because it provides the technical foundation for long-term National Security enhancement through the discovery of new phenomena and the exploration of the potential of such phenomena for Defense applications. It supports the scientific study and experimentation that is the basis for more advanced knowledge and understanding in information, electronic, mathematical, computer, biological and materials sciences.

The Bio/Info/Micro Sciences project will explore and develop potential technological breakthroughs that exist at the intersection of biology, information technology and micro/physical systems to exploit advances and leverage fundamental discoveries for the development of new technologies, techniques and systems of interest to the DoD. Programs in this project will draw upon information and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels.

The Math and Computer Sciences project supports long term national security requirements through scientific research and experimentation in new computational models and mechanisms for reasoning and communication in complex, interconnected systems. The project is exploring novel means of leveraging computer capabilities, including: practical, logical, heuristic, and automated reasoning by machines; development of enhanced human-to-computer and computer-to-computer interaction technologies; innovative approaches to the composition of software; innovative computer architectures; mathematical programs and their potential for defense applications; and new learning mechanisms for systematically upgrading and improving these capabilities.

The Cyber Sciences project supports long term national security requirements through scientific research and experimentation in cybersecurity. Networked computing systems control virtually everything, from power plants and energy distribution, transportation systems, food and water distribution, financial systems, to defense

systems. Protecting the infrastructure on which these systems rely is a national security issue. The Cyber Sciences project will ensure DoD cyber-capabilities survive adversary attempts to degrade, disrupt, or deny military computing, communications, and networking systems. Basic research in cyber security is required to provide a basis for continuing progress in this area. Promising research results will transition to both technology development and system-level projects.

The Electronic Sciences project explores and demonstrates electronic and optoelectronic devices, circuits and processing concepts that will provide: 1) new technical options for meeting the information gathering, transmission and processing required to maintain near-real time knowledge of the enemy and the ability to communicate decisions based on that knowledge to all forces in near-real time; and 2) provide new means for achieving substantial increases in performance and cost reduction of military systems providing these capabilities.

The Materials Sciences project provides the fundamental research that underpins the development and assembly of advanced nanoscale and bio-molecular materials, devices, and electronics for DoD applications that greatly enhance soldier awareness, capability, security, and survivability, such as materials with increased strength-to-weight ratio and ultra-low size, devices with ultra-low energy dissipation and power, novel spectroscopic sources, and electronics with persistent intelligence and improved surveillance capabilities.

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in computing and the computing-reliant subareas of the social sciences, life sciences, manufacturing, and commerce. The project integrates these diverse disciplines to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations.

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	315.033	312.146	322.923	-	322.923
Current President's Budget	293.284	332.146	333.119	-	333.119
Total Adjustments	-21.749	20.000	10.196	-	10.196
• Congressional General Reductions	-	-			
• Congressional Directed Reductions	-	-			
• Congressional Rescissions	-	-			
• Congressional Adds	-	20.000			
• Congressional Directed Transfers	-	-			
• Reprogrammings	-12.436	-			
• SBIR/STTR Transfer	-9.313	-			
• TotalOtherAdjustments	-	-	10.196	-	10.196

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2014	FY 2015
Project: CCS-02: *MATH AND COMPUTER SCIENCES*		
Congressional Add: *Basic Research Congressional Add*	-	5.000

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2014	FY 2015
Congressional Add Subtotals for Project: CCS-02	-	5.000
Project: CYS-01: *CYBER SCIENCES*		
Congressional Add: *Basic Research Congressional Add*	-	5.000
Congressional Add Subtotals for Project: CYS-01	-	5.000
Project: ES-01: *ELECTRONIC SCIENCES*		
Congressional Add: *Basic Research Congressional Add*	-	5.000
Congressional Add Subtotals for Project: ES-01	-	5.000
Project: MS-01: *MATERIALS SCIENCES*		
Congressional Add: *Basic Research Congressional Add*	-	5.000
Congressional Add Subtotals for Project: MS-01	-	5.000
Congressional Add Totals for all Projects	-	20.000

Change Summary Explanation

FY 2014: Decrease reflects below threshold and omnibus reprogrammings and the SBIR/STTR transfer.
FY 2015: Increase reflects congressional adds.
FY 2016: Increase reflects expanded focus in Cyber Sciences.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency											Date: February 2015	
Appropriation/Budget Activity 0400 / 1					R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*				Project (Number/Name) BLS-01 / *BIO/INFO/MICRO SCIENCES*			
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
BLS-01: *BIO/INFO/MICRO SCIENCES*	-	20.355	15.036	6.127	-	6.127	-	-	-	-	-	-

A. Mission Description and Budget Item Justification

This project is investigating and developing the intersections of biology, information technology and micro/physical systems to exploit important technological advances and leverage fundamental discoveries for the development of new technologies, techniques, and systems of interest to the DoD. This research is critical to the development of rapid responses to engineered biological warfare agents, radically new biomolecular computers, improved training and cognitive rehabilitation. Programs in this project will draw upon the information and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels. This project will develop the basic research tools in biology that are unique to the application of biological-based solutions to critical Defense problems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Quantitative Models of the Brain	9.150	10.636	6.127

Description: The Quantitative Models of the Brain program will establish a functional mathematical basis on which to build future advances in cognitive neuroscience, computing capability, and signal processing across the DoD. An important focus of this program will be determining how information is stored and recalled in the brain and other DoD-relevant signals, developing predictive, quantitative models of learning, memory, and measurement. Using this understanding, the program will develop powerful new symbolic computational capabilities for the DoD in a mathematical system that will provide the ability to understand complex and evolving signals and tasks while decreasing software and hardware requirements and other measurement resources. This includes a comprehensive mathematical theory to extract and leverage information in signals at multiple acquisition levels, that would fundamentally generalize compressive sensing for multi-dimensional sources beyond domains typically used. New insights related to signal priors, task priors, and adaptation will enable these advances. This program will further exploit advances in the understanding and modeling of brain activity and organization to improve training of individuals and teams as well as identify new therapies for cognitive rehabilitation (e.g., TBI, PTSD). Critical to success will be the ability to detect cellular and network-level changes produced in the brain during the formation of new, hierarchically organized memories and memory classes, and to correlate those changes with memory function of animals during performance of behavioral tasks.

FY 2014 Accomplishments:
- Demonstrated hyperspectral imaging using 100x fewer measurements than reconstructed pixels.
- Explored the application of compressive sensing concepts to alternate sensing modalities such as x-ray imaging.
- Investigated the potential gains available from compressive sensing within multiple video applications.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** BLS-01 / *BIO/INFO/MICRO SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Leveraged advances in neuroscience and neurological measurements to develop predictive, quantitative models of memory, learning, and neuro-physiologic recovery. ***FY 2015 Plans:*** - Quantify spatio-temporal patterns of neurochemical activity underlying memory formation. - Extend model and brain regions to account for hierarchical organization of memories (procedural, declarative/episodic). - Demonstrate model prediction of knowledge and skill-based memory encoding. - Develop model of memory encoding using non-invasively recorded neural signals. ***FY 2016 Plans:*** - Build a hippocampal-neocortical model of stimulation-based memory enhancement. - Develop sparse multiple input/multiple output nonlinear dynamical modeling methodology for real-time application to electrophysiological recordings. - Develop and apply a new set of classification models for the prediction of behavioral outcomes from the spatio-temporal patterns of electrophysiological recordings in the hippocampus.			
Title: Bio Interfaces ***Description:*** The Bio Interfaces program supports scientific study and experimentation, emphasizing the interfaces between biology and the physical and mathematical/computer sciences. This unique interaction will develop new mathematical and experimental tools for understanding biology in a way that will allow its application to a myriad of DoD problems. These tools will help exploit advances in the complex modeling of physical and biological phenomena. It is also expected that understanding the fundamentals of biology will aid in developing tools to understand complex, non-linear networks. This program will also explore the fundamental nature of time in biology and medicine. This will include mapping basic clock circuitry in biological systems from the molecular level up through unique species level activities with a special emphasis on the applicability to human biology. ***FY 2014 Accomplishments:*** - Experimentally validated canonical spatio-temporal episequences, and developed a minimal dataset for accurate predictions of temporal processes such as cell cycle progression, metabolic cycles, and lifespan. - Refined predictive algorithms of the progression of biological time. - Developed and tested the predictive model or algorithm against a blind panel to predict doubling time, cell cycle progression, metabolism and lifespan metrics. ***FY 2015 Plans:*** - Investigate alternative strategies for treating disease by targeting clocking systems that drive temporal processes such as cell cycle progression and metabolic cycles.	9.705	4.400	-

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Test the ability of predictive algorithms of biological time to enable an economical and easily administered test to assess and predict human circadian phase from blood. - Leverage temporally collected data to test the impact of time on drug efficacy. - Discover and test novel compounds that target oscillatory networks to modulate neurodegenerative disease in an animal model.			
Title: Physics in Biology ***Description:*** Understanding the fundamental physical phenomena that underlie biological processes and functions can provide new insights and lead to unique opportunities for exploiting such phenomena. The Physics in Biology thrust explored the role and impact of quantum effects in biological processes and systems. This included exploiting manifestly quantum mechanical effects that exist in biological systems at room temperature to develop a revolutionary new class of robust, compact, high sensitivity and high selectivity sensors. The quantum phenomena uncovered was demonstrated to control the attraction of insects to humans with the potential to significantly reduce insect bites and thus the transmission of parasitic, bacterial or viral pathogens. ***FY 2014 Accomplishments:*** - Demonstrated prototype quantum biological sensors and measured against equivalent state-of-the-art sensors in order to quantify the increase in sensitivity, selectivity and other performance metrics. - Explored quantum physics-based mechanisms of mosquito bio-sensing related to mosquito attraction to humans for novel, vector-born disease protection against diseases such as malaria or dengue fever.	1.500	-	-
Accomplishments/Planned Programs Subtotals	20.355	15.036	6.127

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*	Project (Number/Name) CCS-02 / *MATH AND COMPUTER SCIENCES*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	-	88.325	118.743	132.336	-	132.336	140.283	152.116	162.783	173.036	-	-

A. Mission Description and Budget Item Justification

This project supports scientific study and experimentation on new computational models and mechanisms in support of long-term national security requirements. The project is exploring novel means of leveraging computer capabilities, including: practical, logical, heuristic, and automated reasoning by machines; development of enhanced human-to-computer and computer-to-computer interaction technologies; innovative approaches to the composition of software; innovative computer architectures; mathematical programs and their potential for defense applications; and new learning mechanisms for systematically upgrading and improving these capabilities. Promising techniques will transition to both technology development and system-level projects.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Big Mechanism	8.090	16.000	23.000

Description: The Big Mechanism program will create new approaches to automated computational intelligence applicable to diverse domains such as biology, cyber, economics, social science, and intelligence. Mastering these domains requires the capability to create abstract yet predictive - ideally causal - models from massive volumes of diverse data generated by human actors, physical sensors, and networked devices. Current modeling approaches are heavily reliant on human insight and expertise, but the complexity of these models is growing exponentially and has now, or will soon, exceed the capacity for human comprehension. Big Mechanism will create technologies to extract and normalize information for incorporation in flexible knowledge bases readily adapted to novel problem scenarios; powerful reasoning engines that can infer general rules from a collection of observations, apply general rules to specific instances, and generate (and compute the likelihood of) the most plausible explanations for a sequence of events; and knowledge synthesis techniques to derive abstract principles and/or create models of extreme complexity consistent with huge volumes of data. Big Mechanism applications will accommodate an operator-in-the-loop by accepting questions posed in human natural language; providing drill-down to reveal the basis for an answer; taking user inputs to improve/correct derived associations, weightings, and conclusions; and querying the operator to clarify ambiguities and reconcile detected inconsistencies. Big Mechanism techniques will integrate burgeoning data into causal models and explore these models for precise interventions in critical areas such as cancer modeling, systems biology, epidemiology, cyber attribution, open-source intelligence, and economic indications and warning.

FY 2014 Accomplishments:

- Formulated initial causal-model-based automated computational intelligence techniques applicable to cancer modeling.
- Developed novel information-extraction technologies suitable for extracting causal fragments from scientific literature.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Developed initial algorithms for assembling causal fragments into larger models. ***FY 2015 Plans:*** - Develop model management techniques for storing, manipulating, and reasoning about tens of thousands of alternative causal models. - Develop techniques to generate plausible causal hypotheses that can be tested in the lab. - Develop tools for operator drill-down, ambiguity clarification, and inconsistency reconciliation. - Develop techniques for automatic query generation given partial/incomplete knowledge/models. ***FY 2016 Plans:*** - Demonstrate prototype technologies in production mode by identifying drug targets and drugs for one or more specific classes of cancer. - Demonstrate automated testing of machine-generated hypotheses. - Create new modes for visualizing and exploring models of huge scope that in their entirety exceed human cognitive capabilities. - Formulate statistical approaches for uncovering causal relationships in numerical data/time series and categorical data/symbol sequences. - Develop and implement scalable algorithms that reveal causality networks in large, complex, heterogeneous datasets.			
Title: Unconventional Processing of Signals for Intelligent Data Exploitation (UPSIDE) ***Description:*** The Unconventional Processing of Signals for Intelligent Data Exploitation (UPSIDE) program will address the open problems facing real-time Intelligence, Surveillance and Reconnaissance (ISR) systems and other power-constrained data-intensive applications. The objective of the UPSIDE program is to create a high-level, non-Boolean computational model and map it directly to the unique functional properties of new emerging devices to achieve significant increases in power efficiency and performance. The UPSIDE program will create a new generation of computing structures that will, in turn, enable revolutionary advances in ISR processing, particularly for DoD applications of embedded, real-time sensor data analysis. Boolean data representations are inherently power-inefficient for many datasets, particularly those produced by noisy analog real-time sensors. The UPSIDE program will establish an unconventional, non-Boolean, computing paradigm to enable new and needed capabilities in the area of sensor data analysis. UPSIDE intends to implement this new computing paradigm in the form of a specialized hardware component termed the inference module (IM). An IM is a computational abstraction, which performs a sophisticated pattern match that maps very efficiently to analog complementary metal-oxide semiconductor (CMOS) circuits and emerging devices. An IM can leverage the physics of an emerging device to compute a pattern match directly. The IM will be first developed through simulation, and then implemented using mixed-signal CMOS technology, as well as using state of the art emerging (non-CMOS) devices. Throughout the program, the inference module will be benchmarked using a DoD-relevant image processing pipeline, to verify gains in both	15.000	21.500	18.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016

computing throughput and power efficiency. The result will be computing infrastructures and functional implementations that demonstrate three orders of magnitude improvement in processing speed and four orders of magnitude improvement in power efficiency. These gains will constitute a disruptive new level of embedded computational efficiency for future real-time sensor systems.

FY 2014 Accomplishments:

- Created conventional image processing pipeline simulation for tracking moving objects in surveillance video for the baseline comparison of UPSIDE image processing metrics.
- Demonstrated that new image processing pipelines using UPSIDE IM exceed goals for equivalent accuracy in object tracking.
- Performed system analysis showing that UPSIDE image processing pipeline can achieve power and performance goals of the program.
- Completed architectural design of a mixed-signal complementary metal-oxide semiconductor (CMOS) chip-based inference module architecture which will be used in the image processing pipeline.
- Fabricated and demonstrated first mixed-signal chips for performing inference module processing for object tracking.
- Measured emerging device specifications for use in simulations showing power and performance of an emerging-device-based inference module in an image processing pipeline.
- Performed initial fabrications of the emerging device(s).
- Began design and development of CMOS support chip containing external digital circuitry required for power, communication and control of the emerging device circuits.

FY 2015 Plans:

- Simulate the selected image processing pipeline utilizing the previously developed inference methodology.
- Develop mixed-signal CMOS based image processing pipeline simulation and validate the simulation of the image processing pipeline using real-time, high-definition video streams.
- Design and fabricate mixed-signal CMOS chip implementation of inference module.
- Fabricate and demonstrate simple circuits based on emerging devices for future inference module development.

FY 2016 Plans:

- Implement full image processing pipeline system in software and provide to a distributed computing environment for maximum digital performance.
- Deliver an inference module based system test bed using the mixed-signal CMOS chip for executing the image processing pipeline with an evaluation in terms of the power, performance and accuracy of the system.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Evaluate the image processing pipeline using the emerging devices showing 1000x performance improvement while reducing power consumption of the processing by 10,000x with no loss in tracking accuracy as compared to the conventional image processing pipeline.			
Title: Young Faculty Award (YFA) ***Description:*** The goal of the Young Faculty Award (YFA) program is to encourage junior faculty at universities and their equivalent at non-profit science and technology research institutions to participate in sponsored research programs that will augment capabilities for future defense systems. This program focuses on speculative technologies for greatly enhancing microsystems technologies, biological technologies and defense sciences. The long-term goal for this program is to develop the next generation of scientists, engineers, and mathematicians in key disciplines who will focus a significant portion of their careers on DoD and National Security issues. The aim is for YFA recipients to receive deep interactions with DARPA program managers, programs, performers, and the user community. Current activities include research in thirteen topic areas spanning from Quantum Science and Technology to Robotics and Supervised Autonomy, Mathematics, Computing, and the Interface of Engineering and Biology. A key aspect of the YFA program is DARPA-sponsored military visits; all YFA Principal Investigators are expected to participate in one or more military site visits to help them better understand DoD needs. ***FY 2014 Accomplishments:*** - Exercised the second year options for successful FY 2013 participants to continue research focused on new concepts for microsystem technologies and defense sciences. - Awarded 28 FY 2014 grants for new two-year research efforts across the topic areas. - Identified the top FY 2013 participants as candidates for selection as a Director's Fellow. During this additional year of funding, researchers further refined their technology to align to DoD needs. - Established approaches to bring appropriate technologies developed through YFA to bear on relevant DoD problems. - Provided awardees mentorship by program managers and engagement with DARPA to encourage future work that focuses on DoD needs. ***FY 2015 Plans:*** - Award Director's Fellowships from top FY 2013 participants. During this additional year of funding researchers will refine their technology further and align to DoD needs. - Exercise second year options for FY 2014 participants to continue research focused on new concepts for microsystem technologies, biological technologies and defense sciences. - Award FY 2015 grants for new two-year research efforts across the topic areas. - Establish approaches to bring appropriate technologies developed through YFA to bear on relevant DoD problems.	15.306	16.501	17.248

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Provide awardees mentorship by program managers and engagement with DARPA to encourage future work that focuses on DoD needs. ***FY 2016 Plans:*** - Award Director's Fellowships for researchers to refine their technology further and align to DoD needs. - Exercise options for FY 2015 participants to continue research focused on new concepts for microsystem technologies, biological technologies, and defense sciences. - Award FY 2016 grants for new two-year research efforts across the topic areas. - Establish approaches to bring appropriate technologies developed through YFA to bear on relevant DoD problems. - Provide awardees mentorship by program managers and engagement with DARPA to encourage future work that focuses on DoD needs.			
Title: Probabilistic Programming for Advancing Machine Learning (PPAML) ***Description:*** The Probabilistic Programming for Advancing Machine Learning (PPAML) program will create an advanced computer programming capability that greatly facilitates the construction of new machine learning applications in a wide range of domains. This capability will increase the number of people who can effectively contribute, will make experts more productive, and will enable the creation of new tactical applications that are inconceivable given today's tools. The key enabling technology is a new programming paradigm called probabilistic programming that facilitates the management of uncertain information. In this approach, developers will use the power of a modern (probabilistic) programming language to quickly build a generative model of the phenomenon of interest as well as queries of interest, which a compiler will convert into an efficient application. PPAML technologies will be designed for application to a wide range of military domains including ISR exploitation, robotic and autonomous system navigation and control, and medical diagnostics. ***FY 2014 Accomplishments:*** - Designed and built the front end of a probabilistic programming system that enables users at a range of skill levels to construct concise, useful models. - Designed and built the back end of a probabilistic programming system that takes as input expressive models written in a probabilistic programming language, queries, and prior data and produces as output an efficient implementation with predictable performance. - Identified and developed three challenge problems from various military domains (quad-rotor sensor fusion, autonomous swarm tracking, and wide-area motion imagery tracking), including collecting and making available sample data of appropriate size. ***FY 2015 Plans:*** - Identify and develop two additional challenge problems from various military domains with increasing levels of complexity and larger data sets.	10.221	14.021	16.088

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Evaluate performance of each probabilistic programming system on each challenge problem. - Extend the front end of a probabilistic programming system with additional functionality, including profilers, debuggers, and model verification/checking tools. - Extend the back end of a probabilistic programming system with additional functionality, such as determining which solver or set of solvers is most appropriate for a given input, improving efficiency of solvers, and compiling inference engines to a range of different hardware targets. ***FY 2016 Plans:*** - Identify and develop two additional challenge problems from different military domains with increasing levels of complexity and larger data sets. - Evaluate the performance of each probabilistic programming system on all existing challenge problems both in terms of the quality of the answers and the levels of resources required. - Continue to extend the front end of a probabilistic programming system with more advanced functionality, including profilers, debuggers, and model verification/checking tools. - Continue to extend the back end of a probabilistic programming system with more advanced functionality, such as determining which solver or set of solvers is most appropriate for a given input, improving efficiency of solvers, and compiling inference engines to a range of different hardware targets. - Evaluate the effectiveness of the developed systems by running a summer school in collaboration with potential transition partners.			
Title: Mining and Understanding Software Enclaves (MUSE) ***Description:*** The Mining and Understanding Software Enclaves (MUSE) program will develop program analyses and frameworks for improving the resilience and reliability of complex software applications at scale. MUSE techniques will apply machine learning algorithms to large software corpora to repair likely defects and vulnerabilities in existing programs and to discover new programs that conform to desired behaviors and specifications. MUSE frameworks will enable robust execution of large-scale and data-intensive computations. Specific technical challenges include persistent semantic artifact generation and analysis, defect identification and repair, pattern recognition, and specification inference and synthesis. MUSE research will improve the security of intelligence-related applications and enhance computational capabilities in areas such as automated code maintenance and revision management, low-level systems implementation, graph processing, entity extraction, link analysis, high-dimensional data analysis, data/event correlation, and visualization. ***FY 2014 Accomplishments:*** - Assembled, cataloged, and developed ontologies for an initial multi-lingual corpus of open source software to serve as target data for software analytics.	4.500	8.000	12.100

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Developed a number of database schema designs to persistently record program analysis outputs, responsive to the queries necessary to drive synthesis and repair activities. ***FY 2015 Plans:*** - Conceive, design, and implement new static and dynamic program analysis techniques structured to interact with a persistent database of program facts collected from deep semantic analysis of a large software corpus. - Design application programming interfaces and implementations of a mining engine that provides support for the efficient injection, querying, inspection, and optimization of the underlying database that is used as the output of program analyses, and the input to software analytics. - Examine repair and synthesis strategies to automatically discover commonalities and fix anomalies in input programs based on mining semantic patterns in the corpus. - Develop deductive database formulations for logical inference, multi-view query systems for machine learning analytics, and probabilistic query engines that collectively enable the implementation of different analytic back ends. - Extend the corpus with richer semantic ontologies and metadata support to deal with diverse language frameworks, environments, and systems at scale. ***FY 2016 Plans:*** - Implement scalable database technologies and mining algorithms that allow the ingestion and analysis of tens of millions of lines of open-source software. - Integrate machine learning algorithms that can direct and assimilate mining activities on analysis artifacts stored in the database. - Evaluate component-level synthesis techniques that automatically construct implementations of complex protocols from discovered specifications. - Identify key challenge problems in automated repair and security analysis, along with novel solutions that directly exploit the latent semantic content in the database.			
Title: Graph-theoretical Research in Algorithm Performance & Hardware for Social networks (GRAPHS) ***Description:*** While the DoD has been extremely effective in deploying rigorous analytical and predictive methods for problems involving continuously valued variables (tracking, signals processing), analytical methods for discrete data such as graphs and networks have not kept pace. Recent evidence has shown that network analysis can provide critical insight when used in DoD-relevant scenarios. In this paradigm, nodes represent items of interest and their relationships or interactions are edges; the result forms a network or graph. Current analysis of large networks, however, is just in its infancy: the composition of real-world networks is understood only at the most coarse and basic details (diameter, degree distribution). In order to implement network techniques efficiently and usefully, a better understanding of the finer mathematical structure of these networks is needed. This	5.213	4.903	2.900

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
includes the development of a comprehensive and minimal mathematical set that characterizes networks of DoD interest and a description of how these quantities vary in both space and time. ***FY 2014 Accomplishments:*** - Developed mathematical models and demonstrated mechanistic methods on use cases in DoD-relevant scenarios including brain science, decision support tools for health and disease prevention and prediction, massive streaming networks, and gene networks. - Investigated and developed probabilistic graph models, statistical measures, and statistical sampling procedures for various graph models. ***FY 2015 Plans:*** - Create a suite of systematic network analysis tools that can be applied to static and dynamic network structures and complex use cases. - Develop near real-time scalable algorithms and models with guaranteed accuracy performance for inference, decision support, and understanding macro-phenomena. ***FY 2016 Plans:*** - Extend previously developed statistical graph models to enable the modeling of multi-scale graphs, heterogeneous and vector link structures. - Deliver code for streaming and scalable algorithms (graph matching, similarity, etc.) for large scale networks to be incorporated into software toolkit. - Deliver data driven graph clustering and analysis methods that allow scientific discovery of complex time varying phenomena.			
Title: Knowledge Representation ***Description:*** The Knowledge Representation thrust, an outgrowth from the Mathematics of Sensing, Exploitation and Evaluation area, will develop much-needed tools to contextualize and analyze heterogeneous scientific data, facilitating field-wide hypothesis generation and testing. This will be accomplished by focusing on two key efforts: the development of domain-agnostic mathematical tools for representing heterogeneous data and domain knowledge in a unified knowledge framework, and domain-specific computational tools to embed observable data within the framework and enable tangible discoveries through computational analysis. To demonstrate the applicability of Knowledge Representation technology to multiple complex systems, the thrust will include validation across multiple disparate scientific and engineering fields. The technology developed under this thrust will revolutionize the process of scientific discovery by efficiently maximizing the potential of large, heterogeneous, multi-scale datasets across numerous complex scientific fields. ***FY 2015 Plans:***	-	12.000	13.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Develop an initial mathematical knowledge framework for representing diverse data types and existing domain knowledge in a domain-agnostic form. - Establish initial scientific and/or engineering use case and example data sets that will be used to validate the knowledge representation framework and tools as they are developed. - Design appropriate tools for ingesting and registering scientific data into a common mathematical representation and demonstrate the tools for example, datasets. ***FY 2016 Plans:*** - Demonstrate data input and information extraction within the mathematical knowledge framework. - Incorporate domain-specific prior knowledge, such as computational models, into the mathematical knowledge framework. - Demonstrate the integration of datasets and prior domain knowledge in one or more scientific and engineering use cases.			
Title: Communicating With Computers (CWC)*	-	8.118	10.000
Description: *Formerly Human and Computer Symbiosis (HCS) The Communicating With Computers (CWC) program will advance the state-of-the-art in human-computer interaction by enabling computers to comprehend language, gesture, facial expression and other communicative modalities in context. Human communication is the process by which an idea in one person's mind becomes an idea in another's. Human language is inherently ambiguous and so humans depend strongly on perception of the physical world and context to make language comprehensible. CWC aims to provide computers with analogous capabilities to sense the physical world; encode the physical world in a perceptual structure; link language to this perceptual encoding; and learn the skills of communication. To accomplish this, CWC will apply and extend research in language, vision, gesture recognition and interpretation, dialog management, cognitive linguistics, and the psychology of visual encoding: these are essential for human communication in the physical world. CWC will also work to extend the communication techniques developed for physical contexts to nonphysical contexts such as virtual constructs in the cyber domain; program evaluations will include tests of this sort of transfer. CWC advances will impact military application areas such as robotics and command and control. ***FY 2015 Plans:*** - Formulate representations for the physical world that can capture the information in a visual scene in a form amenable to annotation and modification by language-based inputs. - Create a semantic framework for gesture, facial expression and other communicative modalities. - Explore methods for determining whether transmitted communications have been successfully received and, if not, what additional communications are most likely to result in success. ***FY 2016 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Implement representations for the physical world and develop connectors to large-scale knowledge bases to enable visual-language synergies. - Develop and demonstrate the capability to make computer inputs using gesture, facial expression and other communicative modalities. - Implement initial techniques for confirming that communications have been successfully received and extrapolating to potentially missing information.			
Title: Building Resource Adaptive Software from Specifications (BRASS) ***Description:*** The Building Resource-Adaptive Software from Specifications (BRASS) program seeks to build an automated framework that permits software systems to seamlessly adapt to changing resource conditions in an evolving operational environment. Effective adaptation is realized through rigorously defined specifications that capture application resource assumptions and resource guarantees made by the environment. Currently, the processes by which applications adapt to environment change via corrective patches is time-consuming, error-prone, and expensive. Predicting the myriad of possible environment changes that an application may encounter in its lifetime is problematic, and existing reactive approaches are brittle and often incorrect. The use of specification-based adaptation will allow BRASS applications to be correctly restructured in real time whenever stated assumptions or guarantees break. This restructuring is optimized to trade off execution fidelity and functionality for continued operation. BRASS will create tools to automatically discover and monitor resource changes, build new analyses to infer deep resource-based specifications, and implement compiler and runtime transformations that can efficiently adapt to resource changes. BRASS will expand on research encountered in the Mining and Understanding Software Enclaves program. ***FY 2015 Plans:*** - Formulate specification techniques that allow the high-level expression of resource constraints inferred from a diverse set of sources including test suites, bug databases, and program analyses. ***FY 2016 Plans:*** - Integrate specifications within an operational environment to monitor resource changes and trigger signals when resource invariants are violated. - Develop compile-time and runtime transformations that ensure survivable operation in the face of unexpected environment changes. - Build validation tools that certify that transformed applications satisfy specification assumptions in the context of new operating environment guarantees.	-	2.500	9.500
Title: Quantifying Uncertainty in Physical Systems	-	6.200	8.550

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Description: The Quantifying Uncertainty in Physical Systems thrust, an outgrowth of the Mathematics of Sensing, Exploitation and Evaluation area, will create the basic mathematics needed to efficiently quantify, propagate and manage multiple sources of (parametric and model) uncertainty to make accurate predictions about and also design stochastic, complex DoD systems. In particular, this will include new methods for scaling Uncertainty Quantification (UQ) methods to multiscale/multiphysics DoD systems; techniques for correcting model-form uncertainty and for predicting rare events; and new methods for decision making, control, and design under uncertain conditions. ***FY 2015 Plans:*** - Initiate development of new dimensional reduction and surrogate model methods with theoretical error bounds for rigorous uncertainty of large-scale, coupled systems. - Initiate development of a new theoretical framework for optimization in the presence of high dimensional uncertain parameters. - Initiate development of new model-form uncertainty approaches that outperform traditional methods such as the Gaussian Process approach for accurate estimation of Quantities of Interest in physical systems. ***FY 2016 Plans:*** - Develop scalable approximation methods with provable error bounds for optimization in the presence of high dimensional uncertain parameters. - Develop scalable Bayesian inference algorithms for inverse methods with orders of magnitude speed-up incorporating the known physical properties of DoD systems. - Implement algorithms for estimation of quantities in physical systems in the presence of uncertainty on emerging high-performance computing platforms. - Derive proofs and theoretical treatment of rare event detection algorithms within risk-based optimization framework.			
Title: Complexity Management Hardware* ***Description:*** *Formerly Cortical Processor The battlefield of the future will certainly have more data generators and sensors that define the information required to execute appropriately. With networked sensors, the variety and complexity of the information streams will be even further extended. This project will explore silicon designs which help alleviate the complexity inherent in next generation systems. These systems will have increasingly large data sets generated by their own multidomain sensors (such as RF and Electro-Optical/Infrared (EO/IR) payloads) as well as new inputs from external sensors that may or may not have been planned for initially. With current programming approaches, there are laborious coding requirements which need to account for new data streams. However, the context provided by these data sets is ever changing, and it is imperative for the integrated electronics to adapt to new information without a prolonged programming cycle. Providing contextual cues for processing of data streams will alleviate the	-	4.000	1.450

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
fusion challenges that are currently faced, and which stress networked battlefield systems. As opposed to the intuition and future-proofing that is required at the programming stage of a current system, the silicon circuit of the future will be able to use contextual cues to adapt accordingly to new information as it is provided. The fundamental aspects of this program will look at various algorithms to explore the ability to use context to adapt to new information. This will start with exploration of the ability to automatically recognize information within streams of data, and then to extract context from the dataset. This will extend to exploiting that context to further refine the processing of an orthogonal data set. Applied research for the program is budgeted in PE 0602303E, Project IT-02. ***FY 2015 Plans:*** - Develop a hierarchical temporal memory (HTM) algorithm including new data representations, low precision and ability to adapt and scale. - Perform benchmark calculations on data streams showing accurate pattern recognition with minimal training times in a variety of applications. ***FY 2016 Plans:*** - Compare various algorithms ability to manage complex data sets. - Quantify the benefits of various architecture approaches to management of large data streams when overlaid with contextual information. - Translate the initial algorithms to high level circuit implementations to show the power and processing requirements.			
Title: Engage ***Description:*** The Engage program developed on-line approaches for complex problem solving in real-world settings by analyzing and adapting performance across large numbers of users. Using unconventional mechanisms and incentives, Engage created an on-line environment for data-driven, interactive, multidisciplinary collaboration among experts and non-experts to address heretofore insolvable challenge problems. This big-data analysis approach identified optimum training strategies, resulting in the development of software that is highly individualized to the user. Engage also addressed the difficult problem of assessing performance in the virtual domain to predict performance in the real world and drive the creation of more effective on-line education and training. Engage technology development was coordinated with the Department of Defense Educational Activity (DoDEA). ***FY 2014 Accomplishments:*** - Developed and released Engage-based software for training additional topics. - Developed novel assessment models for adapting educational technologies to individual users. - Created a collection of research-based technologies that align with national educational standards.	11.815	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Executed an MOU and pilot with DoDEA to incorporate one or more ENGAGE games into DoDEA curriculum. - ENGAGE robotics games were used in over 16K classrooms by over 276K students. - ENGAGE games have been played by over 5 million players (projected to be 13 million by June 2015). - Developed design and simulation tools that allow students and instructors to determine the operation of a complex electro-mechanical system. - Demonstrated the linking between design and prototyping tools that will allow for in-field manufacturing of failed components. - Demonstrated the linking of instructional design and simulation tools with rapid prototyping machines to allow for the troubleshooting and repair of failed components in electro-mechanical systems.			
Title: Strategic Social Interaction Modules (SSIM) ***Description:*** The Strategic Social Interaction Modules (SSIM) program improved military training to include the social interaction skills and abilities warfighters need for successful engagement with local populations. In the current and likely future operational environment, it is imperative to develop rapport with local leaders and civilians as their cooperation and consent will be necessary for successful operations. SSIM emphasized the foundational social skills necessary to achieve cultural understanding in any social setting and the skills necessary for successful interactions across different social groups. These core skills do not require soldiers to have knowledge of a specific culture prior to contact but emphasizes skills for orienting toward and discovering patterns of meaningful social behavior. SSIM developed the requisite training technology, including advanced gaming/simulation techniques, that incorporate new methods for practicing social agility in social encounters, as well as how to discover and adapt to unfamiliar culturally-specific conduct, manners, and practices. SSIM enhanced military effectiveness by enabling close collaborative relationships with local peoples and leaders. ***FY 2014 Accomplishments:*** - Refined the curriculum for SSIM-oriented training based on findings regarding effective social interaction. - Completed the assessment of the effectiveness of SSIM-training to determine direct and indirect effects. - Transitioned SSIM-based training and training simulator to transition partners. - Completed field-testing of prototypes and deployed new training technologies.	10.777	-	-
Title: Mathematics of Sensing, Exploitation and Evaluation (MSEE) ***Description:*** The Mathematics of Sensing, Exploitation and Evaluation (MSEE) program sought to create a comprehensive mathematical theory of information processing, strategy formulation and decision determination. Such a theory incorporates techniques from diverse mathematical disciplines such as Stochastic Process Theory, Harmonic Analysis, Formal Languages and Theoretical Computer Science to construct a common framework wherein the quantitative value of data acquisition may be assessed relative to dynamically-varying context. In addition, the structure accommodates the notion that data acquisition and information processing are coupled, requiring some degree of feedback and control, while simultaneously admitting the	4.853	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
possibility of different logics, such as those that allow for incomplete and time-varying states of knowledge. The result of this effort produced advances in fundamental domains of mathematics with the potential to reshape current DoD approaches to managing the battlespace and supervisory controls. ***FY 2014 Accomplishments:*** - Implemented multiple-modality solutions that demonstrated the effectiveness of a unified approach to sensing. - Created an advanced evaluation test-bed that enabled probative, quantitative assessment of a system's ability to understand scene semantics. - Demonstrated enhanced anomaly detection under varying operating conditions, including production of a single (unified) semantic representation of a scene in the presence of coincident sensor data coming from multiple modalities, some of which comprised electro-optical/IR.			
Title: Computer Science Study Group (CSSG) ***Description:*** The Computer Science Study Group (CSSG) program supported emerging ideas from the computer science academic community to address the DoD's need for innovative computer and information technologies; introduced a generation of junior researchers to the needs and priorities of the DoD; and enabled the transition of those ideas and applications by promoting joint university, industry, and government projects. The CSSG project formalized and focused this research for efficiency and greater effectiveness. ***FY 2014 Accomplishments:*** - Transitioned successful research outcomes from Classes 2010-2011. - Conducted CSSG Continuing Research Series Text and Video Analytics Workshop at Army Research Laboratory. - Conducted a National Security Innovation Workshop at the Institute for Defense Analyses. - Matched funding with government and industry partners for seven Phase 3 technology transition projects.	2.550	-	-
Accomplishments/Planned Programs Subtotals	88.325	113.743	132.336

	FY 2014	FY 2015
Congressional Add: Basic Research Congressional Add ***FY 2015 Plans:*** - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.	-	5.000
Congressional Adds Subtotals	-	5.000

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
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C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*	Project (Number/Name) CYS-01 / *CYBER SCIENCES*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
CYS-01: *CYBER SCIENCES*	-	23.720	58.462	53.774	-	53.774	45.000	47.219	27.000	10.000	-	-

A. Mission Description and Budget Item Justification

The Cyber Sciences project supports long term national security requirements through scientific research and experimentation in cyber security. During the past decade information technologies have enabled important new military capabilities and driven the productivity gains essential to U.S. economic competitiveness. Unfortunately, during the same period, cyber threats have grown rapidly in sophistication and number, putting sensitive data, classified computer programs, and mission-critical information systems at risk. The basic research conducted under the Cyber Sciences project will produce the breakthroughs necessary to ensure the resilience of DoD information systems to current and emerging cyber threats. Promising research results will be transitioned to both technology development and system-level projects.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Automated Program Analysis for Cybersecurity (APAC)	23.720	21.318	10.016

Description: Automated Program Analysis for Cybersecurity (APAC) is developing automated program analysis techniques for mathematically validating specified security properties of mobile applications. This will involve creating new and improved type-based analysis, abstract interpretation, and flow-based analysis methods with far greater ability to accurately demonstrate security with lower instances of false alarms. APAC technologies will enable developers and analysts to identify mobile applications that contain hidden malicious functionality and bar those applications from DoD mobile application marketplaces.

FY 2014 Accomplishments:
- Improved the effectiveness of prototype tools to enable human analysts charged with curating a DoD app store to keep up with a realistic stream of incoming applications.
- Measured the improvement of analyst productivity and effectiveness through further engagements.
- Used measurements against the program metrics to identify prototype tools that are likely candidates for technology transition.
- Identified transition partners and captured specific user operational needs.

FY 2015 Plans:
- Assess and select prototype tools for experimentation or transition based on their performance on program metrics: probabilities of false alarm, missed detection and human analysis time.
- Conduct further engagements to detect malice hidden in mobile applications, in particular race conditions, complex hidden triggers, and application collusion.
- Measure the improvement of analysts ability to bar malware from DoD app stores using the prototype tools.

FY 2016 Plans:
- Run comparative performance evaluations between program-developed malware detection tools and commercially available tools.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** CYS-01 / *CYBER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Engage in experiments and pilot deployments of prototype tools with transition partners running DoD application stores. - Based on user feedback, make improvements to prototypes to enhance usability in the context of DoD application stores.			
Title: SafeWare ***Description:*** The SafeWare program will develop new code obfuscation techniques for protecting software from reverse engineering. At present, adversaries can extract sensitive information from stolen software, which can include cryptographic private keys, special inputs/failsafe modes, proprietary algorithms and even the software architecture itself. Today's state of the art in software obfuscation adds junk code (loops that do nothing, renaming of variables, redundant conditions, etc.) which unfortunately does little more than inconvenience the aggressor. Recent breakthroughs in theoretical cryptography have the potential to make software obfuscation into a mathematically rigorous science, very much like what the Rivest-Shamir-Adleman (RSA) algorithm did for the encryption of messages in the 1970's. The SafeWare program aims to take this very early-stage theory, which in its present form incurs too much runtime overhead to be practical, and re-tool its mathematical foundations such that one day it will be practical and efficient. As with RSA, SafeWare methods will require the solution of a computationally hard mathematical problem as a necessary condition for a successful de-obfuscation attack. SafeWare is addressing basic research issues encountered in Safer Warfighter Computing (SAFER) in PE 0602303E, Project IT-03. ***FY 2015 Plans:*** - Formulate new cryptographic approaches for protecting software from reverse engineering with mathematically proven security properties that are not substantially diminished in effectiveness even if they are fully understood by the adversary. - Develop cryptographic code obfuscation methods for which the increase in adversary work factor scales exponentially with respect to a polynomial increase in program runtime overhead. - Assess the potential for implementing cryptographic code obfuscation techniques on multiprocessor systems. ***FY 2016 Plans:*** - Explore potentially powerful new primitives for cryptographic program obfuscation such as multilinear maps. - Develop alternate notions and models of obfuscation that accommodate specialized aggressor models. - Optimize domain-specific algorithms for obfuscation efficiency.	-	10.000	13.826
Title: Space/Time Analysis for Cybersecurity (STAC) ***Description:*** The Space/Time Analysis for Cybersecurity (STAC) program will develop techniques to detect vulnerabilities to algorithmic complexity and side channel attacks in software. Historically, adversaries have exploited software implementation flaws through buffer and heap overflow attacks. Advances in operating systems have largely mitigated such attacks, so now cyber adversaries must find new ways of compromising software. Algorithmic complexity and side channel attacks are emerging as the next generation of attacks since they depend on intrinsic properties of the algorithms themselves rather than flaws in their implementations. Recent news reports have highlighted the first wave of these attacks (CRIME, BREACH, Hash DoS). The	-	12.144	14.573

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
STAC program seeks to develop new analysis tools and techniques to detect vulnerabilities to these attacks in the software upon which the U.S. government, military, and economy depend. STAC extends work initiated under the Automated Program Analysis for Cybersecurity (APAC) program to address algorithmic complexity and side channel attacks. ***FY 2015 Plans:*** - Present initial program analysis approaches for identifying vulnerabilities to algorithmic complexity and side channel attacks based on both time and space resource usage. - Develop STAC concept of operations, create example resource usage attack scenarios, and define the rules of engagement for competitive experiments between research and adversarial challenge teams. - Identify the initial infrastructure required to support the development of a sufficient number of challenge programs containing known vulnerabilities to support realistic evaluations. ***FY 2016 Plans:*** - Define the formal semantics of the runtime environments in which vulnerable software runs and encode these semantics in a form consumable by automated analysis tools. - Produce initial analysis tools capable of reasoning about data and control flow paths in computer programs, identifying inputs adversaries can use to mount algorithmic complexity attacks, and outputs that adversaries can use to mount side channel attacks. - Perform the first competitive experiment using prototype analysis tools to find vulnerabilities to algorithmic complexity and side channel attacks in a corpus of challenge programs and produce measurements of research progress against program metrics.			
Title: Transparent Computing* ***Description:*** *Previously funded in PE 0601101E, Project CCS-02 The Transparent Computing program will develop technologies to enable the implementation of more effective security policies across distributed systems. The scale and complexity of modern information systems obscures linkages between security-related events, the result being that detection of attacks and anomalies must rely on narrow contextual information rather than complete knowledge of the event's provenance. This shortcoming facilitates attacks such as advanced persistent threats. The Transparent Computing program will address these problems by creating the capability to propagate security-relevant information and ensure component interactions are consistent with established behavior profiles and policies. Transparent Computing technologies are particularly important for large integrated systems with diverse components such as distributed surveillance systems, autonomous systems, and enterprise information systems. ***FY 2015 Plans:*** - Formulate approaches for tracking information flows and other causal dependencies, and recovering event provenance to enable more effective detection of attacks, anomalies, and advanced persistent threats.	-	10.000	15.359

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Develop active/continuous testing and adaptive security policy schemes that adjust security posture and usage controls in response to information provided by distributed protection components. - Introduce dynamic behavioral attestation techniques, and propose and analyze scalable algorithms and implementations. ***FY 2016 Plans:*** - Implement adaptive security policy schemes in software prototypes with flexibility and scalability suitable for use on distributed surveillance systems, autonomous systems, and enterprise information systems. - Perform initial assessments of security policy prototypes in simulated laboratory and cloud environments. - Develop and implement behavioral attestation techniques in software prototypes scalable to big data applications. - Develop and implement causal dependency tracking across software/hardware abstraction layers.			
Accomplishments/Planned Programs Subtotals	23.720	53.462	53.774

	FY 2014	FY 2015
Congressional Add: Basic Research Congressional Add	-	5.000
FY 2015 Plans: - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.		
Congressional Adds Subtotals	-	5.000

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*	Project (Number/Name) ES-01 / *ELECTRONIC SCIENCES*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	-	35.969	37.411	40.401	-	40.401	44.578	36.951	39.796	44.883	-	-

A. Mission Description and Budget Item Justification

This project seeks to continue the phenomenal progress in microelectronics innovation that has characterized the last decades by exploring and demonstrating electronic and optoelectronic devices, circuits and processing concepts that will: 1) provide new technical options for meeting the information gathering, transmission and processing required to maintain near real-time knowledge of the enemy and the ability to communicate decisions based on that knowledge to all forces in near real-time; and 2) provide new means for achieving substantial increases in performance and cost reduction of military systems providing these capabilities. Research areas include new electronic and optoelectronic device and circuit concepts, operation of devices at higher frequency and lower power, extension of diode laser operation to new wavelength ranges relevant to military missions, development of uncooled and novel infrared detector materials for night vision and other sensor applications, development of innovative optical and electronic technologies for interconnecting modules in high performance systems, research to realize field portable electronics with reduced power requirements, and system and component level improvements to provide greater affordability and reliability. Additionally, electronically controlled microinstruments offer the possibility of nanometer-scale probing, sensing and manipulation for ultra-high density information storage "on-a-chip," for nanometer-scale patterning, and for molecular level analysis and synthesis. These microinstruments may also offer new approaches to integration, testing, controlling, manipulating and manufacturing nanometer-scale structures, molecules and devices.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Arrays at Commercial Timescales (ACT)	5.442	5.811	5.301

Description: Phased arrays are critical military subsystems with widespread applications in communications, electronic warfare and radar. The DoD relies heavily on phased arrays to maintain technological superiority in nearly every theater of conflict. The DoD cannot update these high cost specialized arrays at the pace necessary to effectively counter adversarial threats under development using commercial-of-the-shelf components that can undergo technology refresh far more frequently. The Arrays at Commercial Timescales (ACT) program will develop adaptive and standardized digital-at-every-element arrays. New advances in digital circuits at every element in an array panel will allow for ubiquitous phased array technology with heretofore unrealized spectral coverage and capabilities. This program will take a fundamental look at the role of digital arrays and how commonality and aggregation can be affected by emerging capabilities. Simultaneously, this effort will focus on the development of arrays which can quickly create different unique RF personalities/capabilities on top of common digital hardware. The project will demonstrate levels of diversity in the use of the electromagnetic spectrum which are severely limited by the current approach of hand-designing the array with heavily specialized RF beamformers that are unique to each system. This program also has related applied research efforts funded under PE 0602716E, Project ELT-01.

FY 2014 Accomplishments:

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Initiated development of fundamental design techniques suited to common hardware components for phased array elements that can be seamlessly integrated into a wide range of platforms. - Initiated development of fundamental components and sub-systems enabling common array modules, including active interference mitigation technology, analog processing or beamforming techniques, novel channelization techniques, and filter-less transceiver topologies. -Demonstrated energy efficient bit-stream beamforming with 64% power savings and 68% reduction in chip size. ***FY 2015 Plans:*** - Develop very high speed analog-to-digital (ADC) and digital-to-analog (DAC) converters enabling elemental level digital beamforming of wide bandwidth RF signals, approaching an instantaneous bandwidth of 1GHz. - Develop sample clocking architectures and dithering techniques that enable decorrelation of quantization noise across a phased array antenna. - Develop very high bandwidth switch and switch array technologies that can be toggled from an electrically large standoff distance to enable frequency reconfigurable radiating elements for phased array antennas. - Complete a study with simulation results to showcase performance tradeoffs in the ACT common module as the line of commonality moves closer toward the aperture interface. - Investigate transition paths for fundamental technologies into array systems and common modules under development in the applied research portion of this project. ***FY 2016 Plans:*** - Continue to develop fundamental technologies and techniques for enabling common array modules. - Develop a module that combines N-path filtering and active interference cancellation for testing with commercial off-the-shelf components. - Investigate transition paths for fundamental technologies into array systems and common modules under development in the applied research portion of this project.			
Title: Semiconductor Technology Advanced Research Network (STARNet) ***Description:*** The Semiconductor Technology Advanced Research Network (STARNet) program is a government-industry partnership combining the expertise and resources from select defense, semiconductor, and information companies with those of DARPA to sponsor an external set of academic research teams that are focused on specific technology needs set by experts in industry and government. Efforts under this program will remove the roadblocks to achieving performance needed for future sensing, communication, computing, and memory applications. The program involves close collaboration between these experts and the academic base with industry providing 60% of program funding matched by 40% from DARPA. For both industrial and government participants, leveraging shared research funding for high risk, pre-competitive technology explorations for shared technical hurdles is very attractive.	20.000	20.000	20.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016

Research in STARNet is divided into a discovery thrust (ACCEL) and an integration thrust (NEXT) executed by virtual academic centers and focused on combining current or emerging technologies to provide new capabilities. ACCEL seeks to discover new material systems, devices, and novel computing/sensing architectures. NEXT involves projects on advanced analog and mixed signal circuitry, complex system design tools, and alternative computing architectures. As the projects in ACCEL mature, it is expected that they will replace the efforts in NEXT that are based on current standard technologies for integrated circuits.

The STARNet program is unique. It creates a community where industry and government participate as co-sponsors to guide and learn from a large academic research base (including approximately 41 universities, 170 faculty researchers, 605 students, and more than 111 industry associate personnel), with DoD shaping the goals to have direct impact on important long-range DoD needs.

FY 2014 Accomplishments:

- Showed proof-of-concept of novel transistor devices with extremely steep turn-on characteristics, allowing the potential for substantial reductions in operating voltage with correspondingly large reductions in power consumption of military electronics.
- Progressed towards achieving the ultimate scalability of silicon-based computing systems with novel data-centric architectures and innovative parallelism strategies.
- Established a fundamental understanding of multifunctional and spintronics materials, interfaces, architectures and demonstrated primary material synthesis approaches and device concepts towards logic and memory applications.
- Satisfied rapidly increasing DoD need for information processing speed and scalability by designing new strategies using non-deterministic computing paradigms and novel nanodevices to compensate for the increasing unreliability of scaled complementary metal-oxide semiconductor (CMOS) very-large-scale integration (VLSI).
- Established an integrated, networked swarm of pervasive smart sensors and actuators to monitor and control environments such as buildings, cities and ultimately battlefield spaces.
- Demonstrated simulators for accelerator-rich computing architecture, identified the novel communication and storage architecture for power efficient data movement, and explored robust and secure computation architecture.
- Monitored and assessed progress towards technical goals proposed by Centers, including reductions of 100 times in the power consumption of devices, 100 - 10,000 times lower energy consumption in logic switches, 10 - 100 times higher computational energy efficiency, scalability of technologies to sub-10 nanometer dimensions, development of novel computing architectures, and highly energy-efficient information processing systems inspired in the nervous system.

FY 2015 Plans:

- Investigate the feasibility of advanced two-dimensional semiconductor materials for extremely low power devices and develop the nanofabrication methods as well as establish the theory, modeling and simulation tools.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Research fundamental limitations of scaling multifunctional and spintronics materials and examine device characteristics as well as demonstrate the advanced devices. - Develop the scalable silicon-based computing system architecture by exploring the benefits of heterogeneously integrating emerging nano-technologies into silicon-based designs. - Develop statistical foundations of information processing via machine learning frameworks, process-scalable foundations of analog mixed-signal systems using information-based design metrics, neuro-principled information processing architectures for Beyond-CMOS and CMOS fabrics, and accelerate the deployment of beyond-CMOS and CMOS nanoscale fabrics via nanofunctions and nanoprimitives. - Develop components, architecture, data control, and tools for sensor swarm applications such as building energy efficiency, health care delivery, manufacturing and agriculture, and warfighter situational awareness. ***FY 2016 Plans:*** - Design VLSI and analog circuits based on novel steep-turn-on transistor devices for applications such as lower power imagers, pattern recognition, and scavenging self-powered electronics with extremely low energy-delay product. - Develop multifunctional and spintronics devices and fabrication techniques to enable logic and memory circuits with increased complexity. - Develop the scalability of silicon-based computing system concepts into the 2020-2030 timeframe to meet the performance, power and cost demands for DoD applications. - Discover, develop, and demonstrate bio- and neuro-inspired information processing architectures that approach the efficiency of brain computation, while aligning well with emerging beyond-CMOS nanoscale fabrics. - Demonstrate sensor swarm applications for Defense requirements such as warfighter situational awareness and assess system characteristics and potential advantages.			
Title: Direct On-Chip Digital Optical Synthesis (DODOS) ***Description:*** The development of techniques for precise frequency control of RF and microwave radiation in the 1940's revolutionized modern warfare. Frequency control is the enabling technology for RADAR, satellite and terrestrial communications, and positioning and navigation technology, among many other core DoD capabilities. By comparison, frequency control at optical frequencies is relatively immature, comparable to the state-of-the-art of microwave control in the 1930's. The first practical demonstration of optical frequency synthesis, utilizing a self-referenced optical comb, was performed in 1999 and, since that time, the precision and accuracy of optical measurements has improved by four orders of magnitude, including the demonstration of atomic clocks utilizing optical-frequency atomic transitions that far outperform existing technology based on microwave transitions. To date, however, optical frequency control has been constrained to laboratory experiments due to the large size, relative fragility, and high cost of optical comb-based synthesizers. Recent developments in self-referenced optical frequency combs in microscale resonators enable the development of a fully-integrated chip-scale optical frequency synthesizer. Ubiquitous low-cost robust	-	3.100	6.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
optical frequency synthesis is expected to create a similar disruptive capability in optical technology as microwave frequency synthesis did in the 1940's, enabling high-bandwidth coherent optical communications, coherent synthesized-aperture LiDAR, portable high-accuracy atomic clocks, high-resolution standoff gas/toxin detection, and intrusion detection, among other foreseen applications. The Direct On-chip Digital Optical Synthesis (DODOS) program will investigate high-performance photonic components for creating a microscale high-accuracy optical frequency synthesizer in a compact robust package, suitable for deployment in a wide variety of mission-critical DoD applications. Significant challenges in the program include reducing the power threshold and stabilizing microresonator optical combs, developing efficient devices for on-chip second harmonic generation, and characterizing the frequency stability and phase noise of a slave laser locked to the stabilized comb. Applied research for this program is funded within PE 0602716E, Project ELT-01. ***FY 2015 Plans:*** - Optimize wavelength dispersion and low-threshold operation of microresonator based combs. - Explore materials and novel devices for efficient on-chip second harmonic generation. ***FY 2016 Plans:*** - Demonstrate low-threshold octave-spanning microresonator combs suitable for DODOS integration. - Demonstrate methods for stabilizing the phase coherence of a microresonator comb across a broad optical bandwidth. - Characterize the output of a slave laser locked to a stabilized microresonator comb and evaluate the performance relative to promising DoD applications for DODOS technology.			
Title: Next Generation Atomic Clock (NGAC)	-	-	4.600
Description: Atomic clock technology provides the high-performance backbone of timing and synchronization for DoD navigation, communications, Intelligence Surveillance and Reconnaissance (ISR), and Electronic Warfare (EW) systems. Prior DARPA investment in Chip-Scale Atomic Clock (CSAC) technology has led to recent demonstrations of enhanced DoD capabilities, enabled by the wide availability of atomic-quality timing in portable battery-powered applications. The Next-Generation Atomic Clock (NGAC) program will develop a next-generation chip-scale atomic clock, with 100X-1000X improvement in key performance parameters, by employing alternative approaches to atomic confinement and interrogation, with particular focus on developing the component technologies necessary to enable low-cost manufacturing and robust deployment in harsh DoD environments. The NGAC program will develop a Chip-Scale Atomic Clock achieving temperature coefficient of frequency of <10^-15/degrees Celsius and frequency drift < 10^-12/month. This will enable precise timing on low-CSWaP platforms with extended mission duration. In order to achieve these performance metrics, novel approaches to atomic confinement and interrogation will be			

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
explored and new enabling components will be developed. Applied research for this program is funded within PE 0602716E, Project ELT-01. ***FY 2016 Plans:*** - Develop low-CSWaP application-specific laser devices, optical modulators, shutters, and isolators. - Demonstrate integration of application-specific optical components into robust photonic integrated circuits. - Develop techniques for alkali metal vapor pressure control over the full DoD temperature range. - Develop low-CSWaP ultra-high vacuum technology operating without perturbative magnetic fields. - Demonstrate clock operation with integrated enabling component devices.			
Title: Near Zero Energy RF and Sensor Operations (N-ZERO) ***Description:*** The DoD has an unfilled need for a persistent, event driven sensing capability, where physical, electromagnetic and other sensors can be pre-placed and remain dormant until awoken by an external trigger or stimulus. State-of-the-art (SOA) sensors use active electronics to monitor the environment for the external trigger. The power consumed by these electronic circuits limits the sensor lifetime to durations of weeks to months. The Near Zero Power RF and Sensor Operations (N-ZERO) program will extend the lifetime of remotely deployed sensors from months to years. N-ZERO will develop the underlying technologies and demonstrate the capability to continuously and passively monitor the environment and wake-up an electronic circuit upon detection of a specific signature or trigger. Thereafter, sensor lifetime will be limited only by processing and communications of confirmed events or ultimately by the battery self-discharge. This program will investigate emerging materials and devices and quantify their impact on system performance. In particular, a fundamental understanding of the trade space that simultaneously minimizes power consumption, the minimum detectable signal, and the probability of false detection will be explored. This program also has related applied research efforts funded under PE 0602716E, Project ELT-01. ***FY 2016 Plans:*** - Develop fundamental materials, devices, and techniques for low energy collection, processing and detection of sensor and communications signals. - Investigate transition paths for fundamental technologies into radio frequency communications and physical sensor systems under development in the applied research portion of this project.	-	-	1.500
Title: Electronic Globalization ***Description:*** Approximately 66% of all installed semiconductor wafer capacity is in Asia. This creates a significant risk as off-shore manufacturing of microelectronic components could introduce various vulnerabilities to DoD systems that utilize these	-	-	3.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
non-U.S. fabricated electronic components. As the DoD is faced with this globalization reality, it is essential to prevent potential consequences such as reverse engineering, theft of U.S. intellectual property, and non-authorized use of these electronic components in adversary defense systems. The Electronic Globalization program will examine various approaches for trusting circuits in an untrusted environment. It will develop the abilities to design circuits with functionality that is benign in an untrusted environment. Basic Research activity will focus on the characterization of materials and structures which enable the trust of circuitry. This trust will be provided by the ability to create back end of line processing, or other similar mechanisms, to complete or personalize a circuit after it has been through the majority of the traditional supply chain. Applied research for the program is budgeted in PE 0602303E, Project IT-02. ***FY 2016 Plans:*** - Define the value proposition offered by the proposed material, identifying a specific Concepts of Operations (CONOPS). - First pass intrinsic physics-level modeling and simulation of structures and materials. - Design of proof-of-concept test sites. - Fabricate test coupons and characterization of new morphological materials and structures. - Characterization of experimental hardware.			
Title: Microscale Plasma Devices (MPD) ***Description:*** The goal of the Microscale Plasma Devices (MPD) program is to design, develop, and characterize MPD technologies, circuits, and substrates. The MPD program will focus on development of fast, small, reliable, high carrier-density, micro-plasma switches capable of operating in extreme conditions, such as high-radiation and high-temperature environments. Specific focus will be given to methods that provide efficient generation of ions that can perform robust signal processing of radio frequency (RF) through light electromagnetic energy over a range of gas pressures. Applications for such devices are far reaching, including the construction of complete high-frequency plasma-based circuits, and microsystems with superior resistance to radiation and extreme temperature environments. It is envisaged that both two- and multi-terminal devices consisting of various architectures will be developed and optimized under the scope of this program. MPDs will be developed in various circuits and substrates to demonstrate the efficacy of different approaches. MPD-based microsystems are demonstrated in DoD applications where electronic systems must survive in extreme environments. The Basic Research part of this effort is focused on fundamental MPD research and will advance scientific knowledge based on the study of several key MPD design parameters. These parameters include ultra-high pressure and high carrier density regimes. MPD will focus on expanding the design space for plasma devices enabling revolutionary advances in micro-plasma device performance. It is expected that MPD will develop innovative concepts and technologies that are clearly disruptive with respect to the current state of the art in terms of switching speed (less than 100 picoseconds), carrier density (exceeding 1E18 per cubic centimeter), and capable of operation and robustness in extreme high-radiation or high-temperature (600degC) environments.	5.000	2.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Fundamental scientific knowledge derived from MPD is also expected to drive developments in commercialization of MPD technology developed and funded in PE 0602716E, Project ELT-01. ***FY 2014 Accomplishments:*** - Completed optimized microcavity designs achieving parameters and uniformity necessary for < 100 picosecond device switching speeds needed for robust survivability in high power electromagnetic fields. - Finalized studies of plasma in extreme environments (radiation and temperature) to demonstrate robust electronics capable of surviving in harsh environments orders of magnitude longer than current state of art silicon Complementary Metal-Oxide Semiconductor (CMOS). - Determined feasibility of controlling infrared and light via manipulation, absorption and switching utilizing microscale plasmas. - Completed device modeling based on characterization of fabricated microscale plasma devices and provided results to circuit and microsystem integrators for use in DoD system designs. - Continued studies of fundamental frequency, efficiency and power limitations of generating high-power microwave through terahertz (THz) frequency signals, utilizing plasma as a robust, non-linear up-conversion medium. ***FY 2015 Plans:*** - Complete investigations examining scaling properties for plasma devices in terms of size, density, robustness and switching speed. - Finalize studies on fundamental frequency, efficiency and power limitations of generating high-power microwave through terahertz (THz) frequency signals utilizing plasma as a robust, non-linear up-conversion medium. - Complete the optimization of devices that perform from RF through light frequencies. - Transition fundamental research findings into improved commercial modeling simulation and design tool capabilities, enabling DoD relevant applications that require survivability in extreme radiation and temperature environments.			
Title: Micro-coolers for Focal Plane Arrays (MC-FPA) ***Description:*** The Micro-coolers for Focal Plane Arrays (MC-FPA) program will develop low size, weight, power, and cost (SWaP-C) cryogenic coolers for application in high-performance infrared (IR) cameras. It is well known that the sensitivity of an IR focal-plane array (FPA) is improved by cooling its detectors to cryogenic temperatures. The disadvantages of state-of-the-art cryo-coolers are their large size, high power and high cost. On the other hand, thermoelectric (TE) coolers used in low performance IR cameras are relatively small, but are inefficient, and it is difficult to achieve temperatures below 200 Kelvin (K). To reduce IR camera SWaP-C, innovations in cooler technology are needed. This program will exploit the Joule-Thomson (J-T) cooling principle, in a silicon-based Micro Electro-Mechanical Systems (MEMS) technology, to develop and demonstrate wafer-scale integrated micro-cryogenic IR FPA coolers with very low SWaP-C. MEMS microfluidics, piezoelectric MEMS, and complementary metal-oxide semiconductor (CMOS) electronics will be used to demonstrate an integrated cold head and	1.500	1.500	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
compressor, all in a semiconductor chip. This program has related applied research efforts funded under PE 0602716E, Project ELT-01. ***FY 2014 Accomplishments:*** - Designed the cold stage with significantly reduced processing steps (from 20 down to 13) and optimized the design of the J-T valve for 100 mW cooling. - Completed the mask layout for the compressors (5.5 mm X 5.5 mm) and individual inlet and outlet valves. - Finalized the selection of all the parts for the year-1 single-stage micro-cryogenic cooler demonstration. - Completed the cold stage fabrication and 50% for the compressor. - Designed a novel coupling approach between the cold stage and the compressor using a Polydimethylsiloxane (PDMS) coupler. - Developed a model for a two-phase heat transfer and fluid flow in the cold stage. - Demonstrated atomic layer deposition (ALD)-based, nano-scaled compression chamber. - Designed a chip-scale, J-T cold-head for a 640 x 480 extended shortwave infrared (e-SWIR, 1-2.4 micrometer cutoff) FPA with 4-6 micrometer unit cell size. - Developed all the critical technologies for the demonstration of a single-stage micro-cooler with an integrated piezoelectric compressor and cold-head with following metric: 30mm x 20mm x 10mm; 50 g. - Developed an alternative system configuration requiring a pressure ratio of 2:1 instead of 4:1. ***FY 2015 Plans:*** - Demonstrate a single-stage micro-cooler with an integrated piezoelectric compressor and cold-head with the following metric: 30 mm x 20 mm x 10 mm; 50 g. - Finalize design and demonstrate a three stage J-T micro-cooler operating down to 195 K. - Finalize design of a five-stage J-T micro-cooler operating down to 150 K with 350 mW heat lift. - Improve the reconfigurable fluid interconnect developed above and apply such a scheme to improve the fabrication yield of the wafer-scale integrated micro-cryogenic cooler. - Integrate the MEMS compressors and the cold stages into a five-stage wafer-scale integrated micro-cryogenic cooler for the final demonstration. - Demonstrate J-T micro-cooler operating down to 150 K with 350 mW heat lift.			
Title: Diverse & Accessible Heterogeneous Integration (DAHI) ***Description:*** Prior DARPA efforts have demonstrated the ability to monolithically integrate a limited set of different semiconductor types to achieve near-ideal "mix-and-match" capability for DoD circuit designers. Specifically, one such program was the Compound Semiconductor Materials On Silicon (COSMOS) program, in which transistors of Indium Phosphide (InP) could be freely mixed with silicon Complementary Metal Oxide Semiconductor (CMOS) circuits to obtain the benefits of both technologies (very high speed and very high circuit complexity/density, respectively). The Diverse & Accessible Heterogeneous	4.027	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Integration (DAHI) program took this capability to the next level, ultimately offering the seamless co-integration of a variety of semiconductor devices (for example, Gallium Nitride, Indium Phosphide, Gallium Arsenide, Antimonide-Based Compound Semiconductors), micro-electromechanical (MEMS) sensors and actuators, photonic devices (e.g., lasers, photo-detectors) and thermal management structures. This capability revolutionized our ability to build true "systems on a chip" (SoCs) and allowed dramatic size, weight and volume reductions for a wide array of system applications. The Basic Research part of this program focused on the development of new hetero-integration processes and capabilities that were demonstrated in application-specific circuits and transferred into the manufacturing flow. This program has applied research efforts funded in PE 0602716E, Project ELT-01, and advanced technology development efforts funded in PE 0603739E, Project MT-15. ***FY 2014 Accomplishments:*** - Developed new CMOS-compatible processes to achieve heterogeneous integration with diverse types of compound semiconductor transistors, MEMS, and non-silicon photonic devices. - Fabricated and tested heterogeneously integrated ultra-low-noise laser sources and on-chip laser radar systems. - Developed noise measurement methodology with sensitivity beyond state-of-the-art in order to test the advanced lasers and optoelectronic signal sources being developed within DAHI.			
Accomplishments/Planned Programs Subtotals	35.969	32.411	40.401

	FY 2014	FY 2015
Congressional Add: Basic Research Congressional Add	-	5.000
FY 2015 Plans: - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.		
Congressional Adds Subtotals	-	5.000

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

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E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	-	93.010	73.077	70.368	-	70.368	69.966	72.233	73.780	85.138	-	-

A. Mission Description and Budget Item Justification

This project provides the fundamental research that underpins the development and assembly of advanced nanoscale and bio-molecular materials, devices, and electronics for DoD applications that greatly enhance soldier awareness, capability, security, and survivability, such as materials with increased strength-to-weight ratio and ultra-low size, devices with ultra-low energy dissipation and power, novel spectroscopic sources, and electronics with persistent intelligence and improved surveillance capabilities.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Nanoscale/Bio-inspired and MetaMaterials	16.205	15.500	19.750

Description: The research in this thrust area exploits advances in nano/micro-scale and bio-inspired materials, including computationally based materials science, in order to develop unique microstructures, material properties, and functionalities. This area also includes efforts to develop the underlying science for the behavior of materials whose properties have been engineered at the nano/micro-scale level, including metamaterials, bio-inspired materials for sensing and actuation, and materials that are designed to mimic biological materials from molecular to macroscopic function. Specific examples of areas of interest include materials that can self-repair, adapt, and respond for soldier protection against chemical and biological threats and optical based metamaterial imaging systems capable of detecting objects in cluttered environments and around or through structural obscurants.

FY 2014 Accomplishments:
- Designed materials with decoupled property combinations (e.g., strength/density, stiffness/thermal expansion) using architecture-to-property trade space capability.
- Demonstrated fabrication methods amenable to scaling and that permit architectural control capable of maintaining decoupled properties.
- Demonstrated targeted enhancement to material properties (e.g., tailored coefficient of thermal expansion (CTE)/energy dissipation and load bearing stiffness).
- Established manufacturability and amenability to scale up and provided fabrication and characterization data package.
- Initiated development of synthetic methods for preparing large sequence controlled polymer libraries.

FY 2015 Plans:
- Develop a method for screening non-natural polymer libraries for designed properties such as binding to target molecules.
- Develop a method for sequencing non-natural polymers at low concentrations.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Explore and develop modeling tools for the physics of scattering in metamaterials and the application of using ultra-short laser pulses to see and detect objects through various obscurants. ***FY 2016 Plans:*** - Use non-natural polymer synthesis and screening system to create affinity reagents against DARPA defined targets. - Develop strategy to adapt the non-natural polymer synthesis and screening system to generate catalysts. - Investigate engineered optical metamaterials for manipulating optical fields in spatial, spectral and temporal domains to enable a single optical device to simultaneously perform multiple functions in different domains. - Investigate linear refraction metamaterials for minimizing optical aberrations and improving performance of imaging and non-imaging optics over wide angles of light incidence, while minimizing optics size and weight.			
Title: Fundamentals of Nanoscale and Emergent Effects and Engineered Devices	6.500	13.300	19.503
Description: The Fundamentals of Nanoscale and Emergent Effects and Engineered Devices program seeks to understand and exploit a broad range of physical properties and new physics that emerge as a result of material and/or device structure and organization at nano-scale dimensions and/or at extreme temperature and pressure. There are a wide variety of material properties that currently exist only at the nanoscale including quantized current-voltage behavior, very low melting points, high specific heats, large surface to volume ratio, high efficiency catalysis, enhanced radiative heat transfer, and correlated electron effects that arise in low dimensional systems. In addition, extreme high pressure conditions can lead to new material polymorphs or phases with dramatically enhanced physical, mechanical and functional properties. The focus of this thrust is to further characterize these emergent properties and to identify new synthesis approaches to enable access to these properties in stable, bulk material systems suitable for a wide range of DoD applications. The insights gained from research performed under this thrust will enable new, more efficient, and powerful material and device architectures that will benefit many DoD applications including controllable photonic devices that operate over multiple wavelengths, ultra-high sensitivity magnetic sensors, high-throughput biochemical sensors for known and unknown (engineered) molecules, advanced armor, ultra-precision air and water purification systems, and advanced armor protection. ***FY 2014 Accomplishments:*** - Validated computational tools against known high-pressure materials and developed multistep pathways to selected extended solids. - Applied synthesis techniques to, and initiated synthesis of, intermediates projected to lead to selected extended solids. - Initiated development of methods to stabilize extended solids at ambient temperatures and pressures. ***FY 2015 Plans:*** - Continue synthesis of suites of intermediates to lead to selected extended solids. - Characterize the physical, structural, and chemical properties of intermediates synthesized.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Further the development of methods to stabilize extended solids at ambient temperatures and pressures. - Based on computational analysis and experimental results, initiate design retrosynthetic pathways that are synthetically achievable for multistep reaction schemes to fabricate extended solids at reduced pressures. - Identify novel approaches for enabling 3 dimensional (3D) assemblies of nanoscale material constructs into micron-scale structures while preserving desirable nanoscale material properties. - Select candidate nanoscale material systems with superior material properties that are amenable to 3D assembly processes. - Identify promising "pick and place" technologies for assembling 3D micron-scale constructs into cm-scale structures. ***FY 2016 Plans:*** - Continue development of methods to stabilize extended solids at ambient temperatures and pressures. - Demonstrate synthesis and stability to ambient temperature and pressure of high density extended carbon based materials (e.g., clathrates, allotropes, and oxides) at the multimilligram scale. - Demonstrate methods to synthesize bulk cubic boron nitride at reduced pressure with purities of >50%. - Refine and implement development of retrosynthetic pathways that are synthetically achievable for multistep reaction schemes to fabricate extended solids at reduced pressures based on computational analysis and stabilization results. - Demonstrate the ability to assemble micron-scale, 3D, multiple material structures from nanoscale material constructs while preserving desirable nanoscale material properties. - Demonstrate pick and place assembly of cm-scale materials from micron-scale constructs while preserving desirable nanoscale material properties.			
Title: Basic Photon Science	17.889	19.400	22.100
Description: The Basic Photon Science thrust is examining the fundamental science of photons, and their interactions in integrated devices, from their inherent information-carrying capability (both quantum mechanically and classically), to novel modulation techniques using not only amplitude and phase, but also orbital angular momentum. The new capabilities driven by this science will impact DoD through novel approaches to communications, signal processing, spectroscopic sensing, and imaging applications. For example, fully exploiting the computational imaging paradigm and associated emerging technologies will ultimately yield ultra-low size, weight, and power persistent/multi-functional intelligence, surveillance, and reconnaissance systems that greatly enhance soldier awareness, capability, security, and survivability. One focus of this thrust is to explore approaches for optical frequency division and harmonic generation for applications such as time distribution from ultrastable optical clocks, ultra-low phase noise microwaves, frequency references, and table-top sources of coherent X-rays, isolated attosecond pulses, and intense neutron sources for medical and non-medical applications. In addition, this thrust will pursue novel, chip-scale optical frequency comb sources and associated technologies throughout the electromagnetic spectrum for spectroscopic sensing and demonstrate their performance with proof-of-concept studies in targeted applications. These sources will enable and spawn			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
entirely new fields in simultaneous remote sensing, identification, and quantification of multiple trace materials in spectrally cluttered backgrounds. ***FY 2014 Accomplishments:*** - Demonstrated quantum mechanically secure communications at a secure key information rate greater than 50 Mb/s and 5 bits per received photon. - Demonstrated a 30 gigahertz (GHz) oscillator using optical frequency division with a micro-frequency comb. - Demonstrated continuous wave operation of a monolithic solid-state laser with milliwatt average output power for integration into a rack mountable ultra-low noise microwave source. - Fabricated silicon nitride microresonators and bulk electro-optically generated frequency comb sources with multiple comb lines for pulse shaping applications including RF photonic filtering. - Designed pump and seed lasers for optical parametric chirped pulse amplification for improved X-ray generation efficiency in the water window spectral region. - Demonstrated pump lasers with pulse energies of 2 joules at 800 nanometers and 1 millijoule at 1.8 micron wavelengths for efficient extreme ultraviolet and soft X-ray attosecond pulse generation. ***FY 2015 Plans:*** - Demonstrate 30 (GHz) microwave output from a silica disk microresonator-based optical frequency comb and high power photodiodes for chip-based, ultra-low phase noise microwave generation. - Demonstrate on-chip frequency comb and pulse shaping components utilizing indium phosphide based photonic integrated circuit technology and evaluate with bulk scale reference combs. - Demonstrate high flux soft X-ray production in the biologically critical water window spectral region and use this source for preliminary X-ray imaging demonstrations on the nanometer scale in the water window. - Demonstrate high efficiency-per-shot laser driven neutron production and construct increased repetition rate sample target inserter and laser amplifiers to improve overall neutron flux for radiography applications. - Demonstrate and control ultra-high intensity, long wavelength lasers, which can be used to generate high average power, high energy isolated attosecond (the timescale of electron dynamics in atoms and molecules) optical pulses. - Develop and control micro-resonator based frequency comb sources in the visible and mid-infrared spectral region. - Demonstrate proof-of-concept studies of coherent control concepts for frequency comb based spectroscopic sensing. ***FY 2016 Plans:*** - Design a rack mounted package for mode-locked laser based optical frequency division microwave source. - Demonstrate RF photonic bandpass filtering with micro-resonator optical frequency combs. - Demonstrate a remotely operating quartz microwave oscillator slaved via optical frequency comb based free-space (wireless) time and frequency transfer.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrate femtosecond time-resolved imaging at the nanometer scale with soft X-rays generated via high harmonic generation (tabletop scale X-ray source). - Finalize laser design and optimize neutron generation source for laser-driven neutron generation. - Demonstrate stability and characterization capabilities of EUV/Soft X-ray attosecond end-station by measuring and characterizing isolated attosecond (10^-18 seconds) pulses. - Demonstrate proof-of-concept for micro-resonator based comb sources in the ultraviolet spectral region. - Demonstrate proof-of-concept for micro-resonator based comb sources in the far-infrared and THz spectral regions. - Demonstrate massively parallel spectroscopy for the detection of multiple trace species using micro-resonator based optical frequency combs in multiple spectral regions in a lab setting.			
Title: Enabling Quantum Technologies	30.543	19.877	9.015
Description: This thrust emphasizes a quantum focus on technology capabilities including significantly improved single photon sources, detectors, and associated devices useful for quantum metrology, communications, and imaging applications. It will also exploit novel optical nonlinearities that can be used to combine quantum systems with classical coherent pulses to enable secure quantum communications over conventional fiber at rates compatible with commercial telecommunications. In addition, this thrust will examine other novel classes of materials and phenomena such as plasmons or Bose-Einstein Condensates (BEC) that have the potential to provide novel capabilities in the quantum regime, such as GPS-independent navigation via atom interferometry and communications, and ultrafast laser technologies. ***FY 2014 Accomplishments:*** - Demonstrated a single diamond nitrogen vacancy magnetometer with < 10 nm resolution that is compatible with imaging biological systems. - Validated the performance of a compact (< 10 liters) portable optical clock with a timing accuracy 10 times better than satellite GPS clocks. - Demonstrated prototypes for macroscopic quantum communications systems at secure long haul communications distances. - Derived optimal decoupling between secure bit rate and loss in long-haul quantum communications. - Implemented macroscopic quantum communications testbed capable of simulating realistic conditions (loss, noise, and decoherence) through the modern fiber-optic telecommunications grid. ***FY 2015 Plans:*** - Develop compact optomechanical gyroscopes. - Demonstrate 50 nm resolution for magnetic imaging of living cells. - Sense functional changes of electronic spin labels in biomolecules (e.g., proteins, lipids) with high spatial and temporal resolution. - Validate optimized performance of slow-beam-optical-clock.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Integrate prototype macroscopic quantum communications system into quantum communications testbed. - Quantify performance of prototype macroscopic quantum communications system under realistic conditions (loss, noise, decoherence) and over secure long haul communications distances. - Develop an initial mathematical modeling framework for predicting the emergence of quantum behavior in complex systems. ***FY 2016 Plans:*** - Explore analytical techniques for characterizing the emergence of quantum effects in complex systems across scales of time and space. - Design an open source, agent based hardware/software platform for evaluating algorithms for modeling quantum effects in complex systems across multiple scales.			
Title: Fundamentals of Physical Phenomena ***Description:*** The thrust obtained insights into physical aspects of natural phenomena such as magnetospheric sub-storms, fire, lightning, and geo-physical phenomena. New fundamental understandings of these phenomena have enabled the ability to predict and exploit these physical processes. A major emphasis of this thrust was to provide predictive models for the interactions between plasmas and electromagnetic waves across a range of energy and length scales, and into new regimes. Specific efforts that fell under this heading were foundational studies on the initiation, propagation, and attachment of lightning, and their associated emissions; the critical factors affecting magnetospheric sub-storms; and understanding and quantifying the interaction of electromagnetic and acoustic waves with the plasma in flames. ***FY 2014 Accomplishments:*** - Gathered in-situ measurements of oceanic lightning e-fields, current and X-rays using synchronized unmanned air vehicle (UAV), balloon, buoy and lighting mapping array. - Measured electron density within the D region of the ionosphere by measuring the aperiodic irregularities (API) structures formed by high frequency (HF) standing waves from the upward and downward propagating heater beam. - Experimentally measured plasma outflow by HF heating, lower hybrid and Whistler waves generation, very low frequency (VLF) waves generation and propagation into space.	8.873	-	-
Title: MesoDynamical Architectures (Meso) ***Description:*** The Meso program exploited recently discovered physics at small scales to demonstrate transformative communication, sensing, and computing technologies for the DoD. The length scale targeted was between the nanoscale and macroscale, known as mesoscale, and is an important intersection between classical and quantum mechanical effects where new combined phenomenon has emerged. The program was divided into four thrusts: nonlinearity and noise, coherent collective dynamics, information transduction, and coherent feedback control. In each of these thrusts, performers focused on demonstrating specific technologies that have significant impact on DoD capabilities. Technologies included high-performance	13.000	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
frequency sources, transistors operating at 100 times lower power than current state-of-the-art, a hand-held biotoxin detector, and attojoule optical switches. ***FY 2014 Accomplishments:*** - Produced the only topological insulator thin (less than 100 nm) materials in the world with topological surface state dominated conduction up to room temperature. This had previously been observed only at cryogenic temperatures, paving the way for fabrication of practical devices to advance DoD's mission. - Discovered spin torque in topological insulator materials over 10 times larger in magnitude than state-of-art at room temperature, highly promising for advanced memory devices with over 10 times lower power required for switching at the same speed of state-of-art, or switching 10 times faster than state-of-art at the same power. - Demonstrated chip-scale, wavelength insensitive second order Silicon Radio Frequency (RF) photonic filters with ~3 GHz pass-band center frequency, >70 dB of rejection over 66% of the center frequency of operation, and undistorted filter response over high optical powers exceeding 100 mW. This eliminates fabrication, design and stabilization constraints of state-of-art RF filtering schemes and dramatically reduces size, weight, power and cost to enable dense integration of RF/Microwave and complementary metal-oxide semiconductor (CMOS) on-chip for nano-Unmanned Aerial Vehicle. - Integrated microfluidic platform and CMOS electronics into the bio-molecular sensor interface by a heterogeneous integration process with demonstrated capability of detecting 1 pM concentration of a toxin in 100 mM background liquid substance without probes or labels. Detected single mass isotope substitutions in amino acids, and sub-10 pM concentration of a neurotoxin in 500nl of blood serum. Extended the scientific knowledge developed in the project to quantum-tunneling-based platforms capable of enabling multi-functional memory devices and on-chip clocks. - Fabricated the first piezoelectronic transistor with a promising path toward achieving >10,000 ON/OFF ratio at 0.1 volts and better processing efficiency than conventional CMOS. Scaled piezoelectric films with full functionality to 300 nm thickness. Invented a new micrometer-scale Radio Frequency switch application of the piezoelectronic transistor with the promise of superior performance than alternate hardware implementations. - Demonstrated planar, chip-scale single-photon conversion between near-visible and telecommunication optical bands with high efficiency for microWatts drive power levels. - Designed new coherent nano-photonic circuit architectures capable of tolerating large error rates per individual components, using substantial coherent feedback to prevent quantum fluctuation noise buildup through multiple logic stages. - Fabricated robust nano-photonic circuits with multiple components switching at 100s of picoseconds and femto-Joule energy (or about 100 photons).			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Reduced the phase noise of truly Micro Electro-Mechanical Systems (MEMS)/Nano Electro-Mechanical Systems (NEMS) frequency sources to produce the next generation (Phase 3) of devices with better temperature and acceleration stability in a compact package.			
Accomplishments/Planned Programs Subtotals	93.010	68.077	70.368

	FY 2014	FY 2015
Congressional Add: Basic Research Congressional Add	-	5.000
FY 2015 Plans: - Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.		
Congressional Adds Subtotals	-	5.000

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	-	31.905	29.417	30.113	-	30.113	28.535	30.831	40.377	42.377	-	-

A. Mission Description and Budget Item Justification

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in information-intensive subareas of the social sciences, life sciences, manufacturing, and commerce. The project integrates these diverse disciplines to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Living Foundries	10.973	9.644	7.750

Description: The goal of the Living Foundries program is to create a revolutionary, biologically-based manufacturing platform to provide new materials, capabilities, and manufacturing paradigms for the DoD and the Nation. With its ability to perform complex chemistries, be flexibly programmed through DNA code, scale, adapt to changing environments and self-repair, biology represents one of the most powerful manufacturing platforms known. However, the DoD's ability to harness this platform is rudimentary. Living Foundries seeks to develop the foundational technological infrastructure to transform biology into an engineering practice, speeding the biological design-build-test-learn cycle and expanding the complexity of systems that can be engineered. The program will enable the rapid and scalable development of previously unattainable technologies and products (i.e., those that cannot be accessed using known, synthetic mechanisms) leveraging biology to solve challenges associated with production of new materials (e.g., fluoropolymers, enzymes, lubricants, coatings and materials for harsh environments), novel functions (e.g., self-repairing and self-regenerating systems), biological reporting systems, and therapeutics to facilitate new solutions and enhancements to military needs and capabilities. Ultimately, Living Foundries aims to provide game-changing manufacturing paradigms for the DoD, enabling distributed, adaptable, on-demand production of critical and high-value materials, devices and capabilities in the field or on base. Such a capability will decrease the DoD's dependence on tenuous material supply chains that are vulnerable to political change, targeted attack, or environmental accident.

If successful, Living Foundries will do for biology what very-large-scale integration (VLSI) did for the semiconductor device industry: enable the design and engineering of increasingly complex systems to address and enhance military needs and capabilities. Living Foundries will develop and apply an engineering framework to biology that decouples biological design from fabrication, develops and yields design rules and tools, and manages biological complexity through simplification, abstraction, and standardization of both processes and components. The result will be rapid design, construction, implementation and testing of complex, higher-order genetic networks with programmable functionality and DoD applicability. Research thrusts include developing the fundamental tools, capabilities and methodologies to accelerate the biological design-build-test cycle,

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
thereby reducing the extensive cost and time it takes to engineer new systems and expanding the complexity and accuracy of designs that can be built. Specific tools and capabilities include: interoperable tools for design and modeling; automated, modular and standardized fabrication and genome-scale engineering processes; modular regulatory elements, devices and circuits for hierarchical and scalable engineering; standardized test platforms and chassis; and novel approaches to process measurement, validation, and debugging. Applied research for this program is budgeted in PE 0602715E, Project MBT-02. ***FY 2014 Accomplishments:*** - Began research and development on incorporation of new, non-natural components into bio-manufactured materials (including non-natural amino acids and an expanded set of atomic elements) to broaden the set of new materials and functions. - Began initial demonstration of automated, genome-scale cellular engineering process platforms that simultaneously increase the scale and complexity of experimentation and decrease the cost and time to engineer a new production system. - Continued research and development of tools and methodologies to program, reprogram, and enable spatio-temporal control and feedback for engineered systems. - Continued to design and assess production pathways for novel materials. - Developed novel algorithms and software that link the design of genetic systems to their assembly and characterization data to begin integrating the design of systems with their construction and ultimate testing/debugging. - Began development and demonstration of tools to enable engineering of currently intractable chassis for novel and enhanced functionalities and materials production. ***FY 2015 Plans:*** - Examine design tool innovations to enable forward engineering of novel genetic systems. - Investigate design evaluation tools to enable massively parallel testing, validation, and verification of engineered systems. - Continue development of automated and scalable, large-scale DNA assembly and editing tools and processes. - Research new methods for integrated feedback to exploit high volume data generation and inform future designs and processes. ***FY 2016 Plans:*** - Begin demonstrating forward engineering of novel genetic systems using innovative computational design tools. - Implement design evaluation tools for high-throughput testing, validation, and verification of engineered systems. - Implement novel learning systems that enable iterative design of engineered systems using integrated feedback of results to inform subsequent designs. - Incorporate automated and scalable, large-scale DNA assembly, editing tools and processes into automated, integrated design-build-test-learn technologies for engineering novel biological systems. - Develop new chassis for engineering biology for improved metabolic flux for bioproduction.			
Title: Open Manufacturing	3.200	3.197	1.538

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Description: The Open Manufacturing program will reduce barriers to manufacturing innovation, speed, and affordability of materials, components, and structures. This will be achieved by investing in technologies to enable affordable, rapid, adaptable, and energy-efficient manufacturing, to promote comprehensive design, simulation and performance-prediction tools, and exposure to best practices. The applied research component of this program is funded in PE 0602715E, Project MBT-01 under Materials Processing and Manufacturing. ***FY 2014 Accomplishments:*** - Developed a fundamental understanding of the impact on quality features and parameters to establish process windows for new rapid process technologies. - Developed metrology methods to support probabilistic process modeling in metals additive manufacturing and bonded composite processing. - Developed a fundamental understanding of the interaction between electromagnetic fields and refractory metals and metal matrix composites based on particle size and material. ***FY 2015 Plans:*** - Develop basic architecture and statistical environment to enable rapid qualification and certification approaches through the interaction and use of probabilistic models for process, design, and materials. - Demonstrate Micro-Induction Sintering (MIS) method for additive manufacture of metal and/or ceramic materials in complex geometries. - Demonstrate approach to verifying, validating, and quantifying uncertainty in the developed rapid qualification frameworks. ***FY 2016 Plans:*** - Characterize material properties of refractory and metal matrix composites produced using micro-induction sintering process. - Develop fundamental process modeling tools for micro-induction sintering process. - Demonstrate approach to integrate the Open Manufacturing rapid qualification frameworks into a comprehensive computational tool.			
Title: Biological Robustness in Complex Settings (BRICS)* ***Description:*** *Formerly ACE (Advanced Capabilities in Engineering Biology) The Biological Robustness in Complex Settings (BRICS) program will leverage newly developed technologies for engineering biology towards enabling radical new approaches to solving National Security challenges. Engineering biology is emerging as a new field focused on developing the tools to harness the powerful synthetic and functional capabilities of biology. These tools will facilitate design and biological production of new chemicals and materials, sensing capabilities, therapeutics, and numerous	-	8.000	10.825

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
other applications. This rapidly developing technological capability opens the door to new national security applications that have heretofore been out of reach, and offers substantial potential advantages in terms of cost and novel functionality. Fundamental work in this area will focus on understanding the underlying principles of engineering robust and safe microbes and microbial communities that perform as designed over the long-term. This program has applied research efforts funded in PE 0602715E, Project MBT-02. ***FY 2015 Plans:*** - Investigate methods to engineer microorganisms that are stable over long time periods under complex growth conditions. - Investigate methods to engineer communities of microorganisms with reliably controlled population dynamics. - Explore methods to rationally engineer functional microbial communities. ***FY 2016 Plans:*** - Demonstrate methods to engineer organisms that are functionally stable over time in changing growth conditions. - Demonstrate methods to engineer complex communities of microorganisms with reliably controlled population dynamics. - Demonstrate methods to rationally engineer functional microbial communities of increasing complexity.			
Title: Applying Biological Complexity at Scale ***Description:*** Applying Biological Complexity at Scale will pursue new insights derived from biological complexity and living-system dynamics to develop applications to enhance global-scale stability, transform hostile environments, and ensure human well-being. Biological systems operate over an enormous range of spatial, physical, and temporal scales and span individual cells to multi-organism systems. Enhanced understanding of the basic processes associated with biological network interactions and communication will enable novel approaches and technology development to enhance national security, ranging from infectious disease mitigation or prevention, to predicting and leveraging behavior of microbial populations or even distributed human networks. Key advances expected from this research will include the identification of stable, scalable features and mechanisms of biological networks. Such information will allow the determination of a bio-system's state and enable the prediction of state, as well as where there are inflection points that can either be exploited, or that must be preserved in order to maintain equilibrium (e.g., microbial community dynamics and their applications). ***FY 2016 Plans:*** - Investigate dynamics and thresholds for transgene stability/instability in systems of infectious disease vectors. - Study methods for achieving transient phenotypes in infectious disease vectors. - Investigate predictive design rules and engineering approaches for integrated biosystems. - Investigate microbial community evolution and communication as it applies to their application (e.g., microbiome impacts on health or catabolism).	-	-	10.000

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Research large-scale biological system responses to threats and understand defining characteristics of varying ecological states.			
Title: Social Media in Strategic Communication (SMISC)	14.620	6.076	-
Description: The Social Media in Strategic Communication (SMISC) program is developing techniques to detect, classify, measure, and track the formation, development, and spread of ideas and concepts (memes) in social media. These techniques will provide warfighters and intelligence analysts with indications and warnings of adversary efforts to propagate purposefully deceptive messaging and misinformation. Social media creates vulnerabilities that can be exploited to threaten national security and has become a key operating environment for a broad range of extremists. SMISC will develop technology and a new supporting foundational science of social networks that will enable warfighters to defend against malevolent use of social media and to counter extremist influence operations. ***FY 2014 Accomplishments:*** - Refined algorithms for real-time detection and tracking of memes at scale. - Improved specialized algorithms to recognize purposeful or deceptive messaging and misinformation, persuasion campaigns, and influence operations across social media. - Designed algorithms to identify the minimum set of sensors for a given social system based on models used to predict the social dynamics stability distribution and impact on link characteristics. - Designed scalable, efficient, and accurate social malware detection algorithms. - Extended algorithms developed for text-centric social media and micro-blogging to new social multi-media platforms. ***FY 2015 Plans:*** - Integrate algorithms for meme detection and tracking with algorithms for detecting deception, persuasion, and influence operations. - Develop high fidelity diffusion models for messages, narratives, and information across social media. - Combine integrated algorithms with diffusion models to create predictive simulations for the spread of given messages, narratives, and information. - Refine algorithms for sentiment analysis of content on developing social multi-media platforms.			
Title: Vanishing Programmable Resources (VAPR)	3.112	2.500	-
Description: The Vanishing Programmable Resources (VAPR) program will create microelectronic systems capable of physically disappearing (either in whole or in part) in a controlled, triggerable manner. The program will develop and establish an initial set of materials and components along with integration and manufacturing capabilities to undergird a fundamentally new class of electronics defined by their performance and transience. These transient electronics ideally should perform in a manner comparable to Commercial Off-The-Shelf (COTS) systems, but with limited device persistence that can be programmed, adjusted			

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
in real-time, triggered, and/or sensitive to the deployment environment. Applications include sensors for conventional indoor/ outdoor environments (buildings, transportation, and materiel), environmental monitoring over large areas, and simplified diagnosis, treatment, and health monitoring in the field. VAPR will explore transience characteristics of electronic devices and materials as well as build out an initial capability to make transient electronics a deployable technology for the DoD and Nation. The technological capability developed through VAPR will be demonstrated through a final test vehicle of a transient sensor with RF link. A basis set of transient materials and electronic components with sufficient electronic and transience performance is needed to realize transient electronic systems for environmental sensing and biomedical applications. Research and development of novel materials for implementing basic transient electronic components (actives and passives), power supply strategies, substrates and encapsulants as well as development of modes and triggers for transience will form the core of fundamental research activities. Transient components and devices developed in this technical area will form the basis for advanced functional circuit blocks and test systems to be developed in PE 0602716E, Project ELT-01. ***FY 2014 Accomplishments:*** - Characterized transience of alternative semiconductors and other electronic materials for device components. - Began developing multiple transience mechanisms, including demonstrating mechanically, electrically, and optically triggered transience. - Began developing electronic materials that exhibit a useful combination of transience and the necessary physical characteristics required for sufficient electronic performance. - Developed polycarbonate-based materials, stress-engineered substrates, hydrogels, and Complementary-Metal-Oxide-Semiconductor (CMOS) process-comparable thin films to allow fast etching, dissolution, sublimation, and fragmentation mechanisms for control of transience effects. - Developed mechanical, stress, corrosion rate modeling tools to predict transience effects. - Initiated the systematic study of novel transient packaging materials. ***FY 2015 Plans:*** - Establish electronic materials that exhibit a useful combination of transience and the necessary physical characteristics required for sufficient electronic performance. - Enhance device modeling tools that incorporate transience effects.			
Accomplishments/Planned Programs Subtotals	31.905	29.417	30.113

C. Other Program Funding Summary ($ in Millions)

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

C. Other Program Funding Summary ($ in Millions)

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601117E / *BASIC OPERATIONAL MEDICAL SCIENCE*

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
Total Program Element	-	48.066	60.757	56.544	-	56.544	62.807	65.685	67.882	66.456	-	-
MED-01: *BASIC OPERATIONAL MEDICAL SCIENCE*	-	48.066	60.757	56.544	-	56.544	62.807	65.685	67.882	66.456	-	-

A. Mission Description and Budget Item Justification

The Basic Operational Medical Science Program Element will explore and develop basic research in medical-related information and technology leading to fundamental discoveries, tools, and applications critical to solving DoD challenges. Programs in this project address the Department's identified medical gaps in warfighter care related to blast-induced traumatic brain injury as well as health monitoring and the prevention of the spread of infectious disease. Efforts will draw upon the information, computational modeling and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels. For traumatic brain injury, this project will establish a fundamental understanding of brain function, short-term memory and the mechanism(s) of injury induced by exposure to blast. To enable in-theater, continuous analysis and treatment of warfighters, this project will also explore diagnostic and therapeutic approaches, such as the use of bacterial predators as therapeutics against infections caused by antibiotic-resistant pathogens. Advances in this area may be used as a preventative measure to mitigate widespread disease.

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	49.500	49.848	44.700	-	44.700
Current President's Budget	48.066	60.757	56.544	-	56.544
Total Adjustments	-1.434	10.909	11.844	-	11.844
• Congressional General Reductions	-	-			
• Congressional Directed Reductions	-	-			
• Congressional Rescissions	-	-			
• Congressional Adds	-	10.909			
• Congressional Directed Transfers	-	-			
• Reprogrammings	-	-			
• SBIR/STTR Transfer	-1.434	-			
• TotalOtherAdjustments	-	-	11.844	-	11.844

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2014	FY 2015
Project: MED-01: *BASIC OPERATIONAL MEDICAL SCIENCE*		
Congressional Add: *Basic Research Congressional Add*	-	10.909
Congressional Add Subtotals for Project: MED-01	-	10.909

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601117E / *BASIC OPERATIONAL MEDICAL SCIENCE*

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2014	FY 2015
Congressional Add Totals for all Projects	-	10.909

Change Summary Explanation

FY 2014: Decrease reflects the SBIR/STTR transfer.

FY 2015: Increase reflects congressional add.

FY 2016: Increase reflects exploration of new methods to maintain and optimize warfighter health, and harness biological technologies and systems.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT)	40.500	49.848	33.400

Description: The Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program will develop the underlying technologies to rapidly respond to a disease or threat and improve individual readiness and total force health protection by providing capabilities which are currently available only in centralized laboratories in the U.S. to non-tertiary care and individual settings. ADEPT will develop and exploit synthetic biology for the in vivo creation of nucleic acid circuits that continuously and autonomously sense and respond to changes in physiologic state and for novel methods to target delivery, enhance immunogenicity, or control activity of vaccines, potentially eliminating the time to manufacture a vaccine ex vivo. ADEPT advancements to control cellular machinery include research to optimize orthogonality and modularity of genetic control elements; identify methods to increase sensitivity and specificity; and demonstrate methods to control cellular machinery in response to changes in physiological status. ADEPT will develop methodologies for measuring health-specific biomarkers from a collected biospecimen to enable diagnostics at the point-of-need or resource limited clinical facilities (point-of-care), in-garrison or deployed. Additionally, ADEPT will develop techniques that will enable the rapid establishment of transient immunity through stimulation of the production of components of the immune system to impart effective but temporary protection. This transient immunity would bridge the time gap between the delivery of a vaccine and the development of a long term protective immune response. Applied research efforts are budgeted in PE 0602115E, Project BT-01.

FY 2014 Accomplishments:

- Demonstrated in mammalian cells the function of a synthetic circuit that can integrate multiple signals associated with health status and respond with a targeted change in cell function.
- Demonstrated the ability to generate synthetic nucleic acid and protein circuit components that respond to an exogenously supplied small molecule drug trigger.
- Demonstrated biostabilization reagents/materials with biospecimen types and physical formats appropriate for integration into devices for collection and transport of patient samples for diagnostic analysis, and integration into on-person diagnostic devices.
- Demonstrated signal amplification methods in conjunction with processing/assay methods.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601117E / *BASIC OPERATIONAL MEDICAL SCIENCE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Optimized sample preparation methods and tested efficacy using biospecimens representative of those either self-collected under low-resource settings or collected by trained professionals at the physician-office settings to assist the diagnosis of an individual. - Developed advanced materials for incorporation in disposable diagnostic devices. - Optimized advanced microfluidic methods for no/low power flow control. - Demonstrated delivery of synthetic oligonucleotide constructs to cells appropriate to produce an antibody response. - Demonstrated antibody and immunoadhesin production targeted to specific disease classes. - Optimized antibody sequence for maximal therapeutic strength of immune response in vivo.			
FY 2015 Plans: - Collect serum from ill, convalescent, or immunized humans and identify two or more antibodies that in combination provide disease-specific protection. - Demonstrate ability to administer nucleic acid encoding multiple antibodies to protect against existing, unmet, clinical targets; emerging global infectious diseases; and known, engineered biothreats. - Demonstrate onset of protection within hours after delivery and duration of therapeutic response greater than IV administered antibodies. - Demonstrate protective response and duration of antibody-encoding nucleic acid constructs greater than that conferred by administration of preformed antibodies against infectious disease in a large animal model. - Demonstrate optimized, high sensitivity assay methods for protein and nucleic acid biomarkers, suitable for incorporation in deployable devices. - Demonstrate advanced materials properties and incorporation of developed materials into disposable assay formats. - Demonstrate advanced methods for reagent stabilization and delivery for assays developed for deployable devices. - Demonstrate sample preparation methods in conjunction with developed assays and quantify performance metrics. - Demonstrate performance of developed assays using advance no/low power microfluidic methods. - Measure performance of developed diagnostic methods and demonstrate capability to measure clinically relevant analyte levels in appropriate biospecimen matrices. - Demonstrate in mammalian cells the function of a synthetic circuit that can control the timing and level of expression of a protein when expressed from an RNA-based expression vector. - Demonstrate in mammalian cells the function of a synthetic circuit that can integrate at least two physiological signals associated with a change in health status and respond to at least two exogenously added small molecules, and respond with a targeted change in cell state. - Demonstrate the ability to generate a synthetic antibody via continuous evolution that can specifically bind to a defined target in mammalian cells.			

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601117E / *BASIC OPERATIONAL MEDICAL SCIENCE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Investigate non-traditional approaches to treating infectious diseases. ***FY 2016 Plans:*** - Establish biodistribution maps in appropriate models resulting from varied delivery methods, formulations, and devices relevant to nucleic acid constructs for antibody production. - Demonstrate protection conferred by delivery of nucleic acid constructs encoding two or more antibodies in validated infectious disease animal model. - Deliver high-sensitivity assay methods for protein and nucleic acid biomarkers for incorporation into deployable devices. - Deliver advanced materials for incorporation into disposable assay formats. - Deliver advanced methods for reagent stabilization and delivery for incorporation into deployable devices. - Deliver sample preparation methods for incorporation into deployable devices. - Demonstrate optimized performance of developed bacterial/viral detection methods, assays, and materials using advanced no/low power microfluidic methods.			
Title: Harnessing Biological Systems ***Description:*** The Harnessing Biological Systems program will explore fundamental approaches to applying the advantages of nature's building blocks and principles in the design of biological technologies and systems. Rather than creating biomimetic designs that imitate naturally evolved capabilities this program seeks to transition to a biocentric design approach, developing tools and understanding mechanisms to leverage evolutionary advances from the start. Key advances expected from this research include identifying the underlying mechanisms by which predatory bacteria prey upon and consume other antibiotic-resistant bacteria that are pathogenic to humans. This approach represents a significant departure from conventional antibacterial therapies that rely on small molecule antibiotics. This thrust will also investigate the adaptability of microorganisms as well as the process for microbial community evolution. Advances in these areas may be applied in a range of biological technologies including the development of novel therapeutics and biocentric sensors. ***FY 2016 Plans:*** - Investigate predator effectiveness against pathogens of interest. - Initiate basic science studies of the relevant underlying mechanisms of predation. - Begin basic science studies to enhance understanding of biological adaptability in response to external pressures. - Identify and understand fundamental mechanisms that control the transition between unicellular and multicellular function. - Examine biological basis for naturally occurring evolutionary advances. - Investigate novel methods to integrate evolved biological traits. - Research basic science processes by which bacteria grow and spread throughout a community.	-	-	10.103
Title: Analytics and Adaptation of Human Resilience	-	-	13.041

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601117E / *BASIC OPERATIONAL MEDICAL SCIENCE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Description: The Analytics and Adaptation of Human Resilience program will explore new methods to maintain and optimize warfighter health in response to environmental insults such as new and emerging infectious diseases. Projects in this area will apply recent advances in comparative biology, genetic sequencing, omics technologies, and bioinformatics to develop new tools for modulating health to ensure warfighter readiness. One approach to achieve this goal is identifying the fundamental mechanisms that enable certain species to be tolerant to various environmental insults. Genomic and physiological analyses of a wide array of resilient animal species may be combined with sophisticated algorithms to identify important patterns of survival. By analyzing patterns in the underlying variability of host responses for resilient animals, one may formulate a survival blueprint to restore and maintain warfighter homeostasis in response to infection. This approach is orthogonal to traditional infectious disease research, which primarily relies on reducing the pathogen load through drug intervention. Projects within this program may enable discovery of novel methods to optimize human health against infectious disease such as multi-drug resistant pathogens. ***FY 2016 Plans:*** - Develop human-relevant animal models of infection across multiple resilient species. - Apply diagnostic technologies that can rapidly detect pathogen load and characterize the different stages of infection in multiple animal species. - Correlate experimental results with bioinformatics datasets to discover key markers of tolerance. - Develop a bioinformatics database to house acquired clinical retrospective data.			
Title: Human Assisted Neural Devices ***Description:*** The Human Assisted Neural Devices program developed the scientific foundation for understanding the language of the brain for application to a variety of emerging DoD challenges, including improving performance on the battlefield and returning active duty military to their units after injury. This required an understanding of neuroscience, significant computational efforts, and new material design and implementation. Key advances from this research include determining the nature and means through which the brain utilizes sensory inputs to plan and execute behavioral outputs, and discovering the mechanisms and dynamics underlying neural computation and reorganization. These advances enabled restoration of sensorimotor function through the use of devices programmed to bridge gaps in the injured brain. Further, modeling of the brain progressed to an unprecedented level with this novel approach. A key aspect of this effort was to develop non-destructive neuronal imaging and control techniques that are capable of rapid analysis and interpretation of brain tissue alterations at the cellular scale. Additional research under this effort generated new methodologies to understand the structural and functional relationships between individual neurons through direct, high-resolution, optical imaging of neuron populations of interest as well as the entire brain. ***FY 2014 Accomplishments:*** - Demonstrated the ability of non-human primates to perform a dexterous sensorimotor task through the use of a neural interface, without the use of neural spike recordings.	7.566	-	-

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601117E / *BASIC OPERATIONAL MEDICAL SCIENCE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Explored initial models of the brain driven by understanding of the physical connections between individual neurons of highly trained animals conducting a specific task. - Generated initial, high-resolution, optical connectivity activity data and corresponding very-large neural data sets.			
Accomplishments/Planned Programs Subtotals	48.066	49.848	56.544

	FY 2014	FY 2015
Congressional Add: Basic Research Congressional Add	-	10.909
FY 2015 Plans: Supports increased efforts in basic research that engage a wider set of universities and commercial research communities.		
Congressional Adds Subtotals	-	10.909

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

F. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
Total Program Element	-	121.152	159.790	114.262	-	114.262	109.069	109.817	120.852	116.651	-	-
BT-01: *BIOMEDICAL TECHNOLOGY*	-	121.152	159.790	114.262	-	114.262	109.069	109.817	120.852	116.651	-	-

A. Mission Description and Budget Item Justification

This Program Element is budgeted in the applied research budget activity because it focuses on medical related technology, information, processes, materials, systems, and devices encompassing a broad spectrum of DoD challenges. Bio-warfare defense includes the capability to predict and deflect evolution of natural and engineered emerging pathogen threats, and therapeutics that increase survivability within days of receipt of an unknown pathogen. Continued understanding of infection biomarkers will lead to development of detection devices that can be self-administered and provide a faster ability to diagnose and prevent widespread infection in-theater. Other battlefield technologies include a soldier-portable hemostatic wound treatment system, capability to manufacture field-relevant pharmaceuticals in theater, and a rapid after-action review of field events as a diagnostic tool for improving the delivery of medical care and medical personnel protection. Improved medical imaging will be approached through new physical properties of cellular metabolic activities. New neural interface technologies will reliably extract information from the nervous system to enable control of the best robotic prosthetic-limb technology. To allow medical practitioners the capability to visualize and comprehend the complex relationships across patient data in the electronic medical record systems, technologies will be developed to assimilate and analyze large amounts of data and provide tools to make better-informed decisions for patient care. In the area of medical training, new simulation-based tools will rapidly teach increased competency in an open and scalable architecture to be used by all levels of medical personnel for basic and advanced training. Advanced information-based techniques will be developed to supplement warfighter healthcare and the diagnosis of post-traumatic stress disorder (PTSD) and mild traumatic brain injury (mTBI). This project will also pursue applied research efforts for dialysis-like therapeutics. FY 2015 Biomedical Technology program funding includes 114.8 million of base funding and 45.0 million of Ebola emergency funding.

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	114.790	112.242	100.603	-	100.603
Current President's Budget	121.152	159.790	114.262	-	114.262
Total Adjustments	6.362	47.548	13.659	-	13.659
• Congressional General Reductions	-	-			
• Congressional Directed Reductions	-	-			
• Congressional Rescissions	-	-			
• Congressional Adds	-	47.548			
• Congressional Directed Transfers	-	-			
• Reprogrammings	9.755	-			
• SBIR/STTR Transfer	-3.393	-			
• TotalOtherAdjustments	-	-	13.659	-	13.659

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2014	FY 2015
Project: BT-01: *BIOMEDICAL TECHNOLOGY*		
Congressional Add: *Ebola Response and Preparedness Congressional Add (Emergency Funds)*	-	45.000
Congressional Add: *Biomedical Congressional Add*	-	2.548
Congressional Add Subtotals for Project: BT-01	-	47.548
Congressional Add Totals for all Projects	-	47.548

Change Summary Explanation

FY 2014: Increase reflects reprogrammings offset by the SBIR/STTR transfer.
FY 2015: Increase reflects congressional adds. The Ebola Response and Preparedness Congressional Add is non-OCO emergency funding.
FY 2016: Increase reflects expanded focus in brain and prosthetic interface systems research.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT)	29.153	26.000	24.700

Description: The overarching goal of the Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program is to increase our ability to rapidly respond to a disease or threat and improve individual readiness and total force health protection by providing centralized laboratory capabilities at non-tertiary care settings. ADEPT will focus on the development of Ribonucleic Acid (RNA)-based vaccines, potentially eliminating the time and labor required for traditional manufacture of a vaccine while at the same time improving efficacy. Additionally, ADEPT will develop methods to transiently deliver nucleic acids for vaccines and therapeutics, and kinetically control the timing and levels of gene expression so that these drugs will be safe and effective for use in healthy subjects. ADEPT will also focus on advanced development of key elements for simple-to-operate diagnostic devices. A companion basic research effort is budgeted in PE 0601117E, Project MED-01.

FY 2014 Accomplishments:
- Demonstrated ability to manipulate the type of immune response induced by RNA-based vaccines.
- Demonstrated ability to target delivery of RNA-based vaccines to specific cell types.
- Developed novel methodologies to deliver nucleic acid constructs encoding one or hundreds of antibodies identified from immunized or convalescent patients.
- Demonstrated delivery of nucleic acids that transiently produce multiple antibodies.
- Performed quantitative comparison of room temperature assay methods appropriate for integration in devices for low-resourced settings.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602115E / *BIOMEDICAL TECHNOLOGY*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrated initial component integration and defined performance metrics for advanced diagnostic device prototypes suitable for operations in remote clinic and low-resourced settings. ***FY 2015 Plans:*** - Demonstrate ability to control the time duration of therapeutic response to viral, bacterial, and/or antibiotic-resistant bacterial pathogens suitable for clinical use and rapid public health responses. - Investigate targeted delivery of nucleic acid constructs to specific cell types. - Demonstrate feasibility for controlling pharmacokinetics and immunity modulation components to enable a more potent and broader immune response to viral, bacterial, and/or antibiotic resistant bacterial pathogens. - Develop designs for RNA-based vaccines to enable transition to human clinical trials. - Develop designs for initial diagnostic device prototypes, based on highest performing components. - Produce first-generation, integrated diagnostic prototypes designed for relevance to physician office, remote clinic, and low-resourced settings. - Measure quantitative performance of first-generation, integrated diagnostic device prototypes and determine modifications required for performance improvements. ***FY 2016 Plans:*** - Optimize formulation of transient nucleic acid formats for storage stability at room temperature for at least six months. - Demonstrate continuous production of nucleic acid formats for transient immunity to viral, bacterial, and/or antibiotic-resistant bacterial pathogens for population-scale use. - Submit Investigational New Drug (IND) application for transient nucleic acid-based formats against infectious disease. - Incorporate device optimizations identified as a result of first-generation integrated diagnostic device testing. - Produce integrated diagnostic device prototypes designed for relevance to physician office, remote clinic, and low-resourced settings. - Measure quantitative performance of integrated diagnostic device prototypes.			
Title: Dialysis-Like Therapeutics ***Description:*** Sepsis, a bacterial infection of the blood stream, is a significant cause of injury and death among combat-injured soldiers. The goal of this program is to develop a portable device capable of controlling relevant components in the blood volume on clinically relevant time scales. Reaching this goal is expected to require significant advances in sensing in complex biologic fluids, complex fluid manipulation, separation of components from these fluids, and mathematical descriptions capable of providing predictive control over the closed loop process. The envisioned device would save the lives of thousands of military patients each year by effectively treating sepsis and associated complications. Additionally, the device may be effective as a medical countermeasure against various chemical and biological (chem-bio) threat agents, such as viruses, bacteria, fungi, and toxins.	20.000	19.492	6.073

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Applied research under this program further develops and applies existing component technologies and then integrates these to create a complete blood purification system for use in the treatment of sepsis. Included in this effort will be development, integration and demonstration of non-fouling, continuous sensors for complex biological fluids; implementation of high-flow microfluidic structures that do not require the use of anticoagulation; application of intrinsic separation technologies that do not require pathogen specific molecular labels or binding chemistries; and refinement of predictive modeling and control (mathematical formalism) with sufficient fidelity to enable agile adaptive closed-loop therapy. ***FY 2014 Accomplishments:*** - Integrated biocompatible high-flow fluid manipulation and intrinsic separation technologies into a breadboard device for the treatment of sepsis. - Used feedback from initial animal model testing to inform the development of an integrated device for additional safety and efficacy studies in a large-animal sepsis model. - Proceeded with regulatory approval process and initiated plan for investigational device exemption submission. ***FY 2015 Plans:*** - Manufacture a prototype device that integrates label-free separation technologies, high-flow fluidic architectures, and non-thrombogenic coatings for testing. - Evaluate the efficacy of the label-free separation technologies in a small-animal model. - Refine the prototype device design based on animal testing results to inform development of a standalone benchtop integrated device. - Establish a clinically relevant model of sepsis in a large animal model in order to validate efficacy of separation technologies at removing pathogens and other sepsis mediators. - Perform biocompatibility studies of each component of the device to ensure safety in the integrated system. ***FY 2016 Plans:*** - Perform safety and efficacy studies in a large-animal sepsis model. - Initiate regulatory approval submission package with safety and efficacy data.			
Title: Warrior Web ***Description:*** Musculoskeletal injury and fatigue to the warfighter caused by dynamic events on the battlefield not only impact immediate mission readiness, but also can have a deleterious effect on the warfighter throughout his/her life. The Warrior Web program will mitigate that impact by developing an adaptive, quasi-active, joint support sub-system that can be integrated into current soldier systems. Because this sub-system will be compliant and transparent to the user, it will reduce the injuries sustained by warfighters while allowing them to maintain performance. Success in this program will require the integration	12.000	6.000	6.000

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
of component technologies in areas such as regenerative kinetic energy harvesting to offset power/energy demands; human performance, system, and component modeling; novel materials and dynamic stiffness; actuation; controls and human interface; and power distribution/energy storage. The final system is planned to weigh no more than 9kg and require no more than 100W of external power. Allowing the warfighter to perform missions with reduced risk of injuries will have immediate effects on mission readiness, soldier survivability, mission performance, and the long-term health of our veterans. ***FY 2014 Accomplishments:*** - Leveraged open source biomechanical model to iterate design. - Completed development of component technologies based on results of preliminary component technology reviews and government testing. - Initiated design of full Warrior Web system. ***FY 2015 Plans:*** - Conduct preliminary review of Warrior Web designs and refine approach as necessary. - Finalize open source biomechanical models to be leveraged for the Warrior Web system evaluation. - Mature design of Warrior Web system and continue parallel technology development. - Conduct preliminary evaluation of prototype Warrior Web systems via soldier tests in laboratory environment. ***FY 2016 Plans:*** - Revise full suit design and implementation based on laboratory evaluations. - Conduct final evaluation of prototype system through soldier tests in relevant military environments. - Coordinate military transition of the technology.			
Title: Restoration of Brain Function Following Trauma ***Description:*** The Restoration of Brain Function Following Trauma program will exploit recent advances in the understanding and modeling of brain activity and organization to develop approaches to treat traumatic brain injury (TBI). Critical to success will be the ability to detect and quantify functional and/or structural changes that occur in the human brain during the formation of distinct new memories, and to correlate those changes with subsequent recall of those memories during performance of behavioral tasks. This program will also develop neural interface hardware for monitoring and modulating neural activity responsible for successful memory formation in a human clinical population. The ultimate goal is identification of efficacious therapeutics or other therapies that can bypass and/or recover the neural functions underlying memory, which are often disrupted as a consequence of TBI. This program is leveraging research conducted under the Human Assisted Neural Devices effort in Program Element 0601117E, Project MED-01. ***FY 2014 Accomplishments:***	8.000	9.700	15.800

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Identified neural codes underlying optimal memory formation. - Optimized electrodes for chronic, indwelling recording and stimulation. ***FY 2015 Plans:*** - Identify commonalities of neural codes underlying memory formation. - Identify distinctions between neural codes underlying different classes of memories. - Identify expert memory codes for the formation of memory associations between pairs of elements (e.g., objects, locations, actions). - Develop portable computational device with integrated computational model of human memory formation. - Demonstrate task-specific improvement/restoration of memory performance in a memory task via hippocampal stimulation. ***FY 2016 Plans:*** - Refine computational model of memory toward distinguishing underlying neural activity related to forgotten memories in three categories (e.g., objects, places, faces) and spatial and non-spatial associations. - Identify optimal stimulation parameters for improving spatial memory. - Utilize defined biomarkers of memory encoding and retrieval to adaptively modulate patterned electrical stimulation to dynamically drive neural networks into states optimized for memory encoding and retrieval processes. - Determine the long-term signatures underlying stimulation-induced memory restoration. - Design, develop and validate both external and implantable hardware and software systems for an integrated memory restoration system. - Demonstrate the ability for a computational model of memory to use long-term neurophysiological activity to predict and restore memory. - Submit initial, novel devices for regulatory approval.			
Title: Neuro-Adaptive Technology ***Description:*** Building upon technologies developed under the Military Medical Imaging program budgeted in this project, the Neuro-Adaptive Technology program will explore and develop advanced technologies for real-time detection and monitoring of neural activity. One shortcoming of today's brain functional mapping technologies is the inability to obtain real-time correlation data that links neural function to human activity and behavior. Understanding the structure-function relationship as well as the underlying mechanisms that link brain and behavior is a critical step in providing real-time, closed-loop therapies for military personnel suffering from a variety of brain disorders. Efforts under this program will specifically examine the networks of neurons involved in Post-Traumatic Stress Disorder (PTSD), Traumatic Brain Injury (TBI), depression, and anxiety as well as determine how to best ameliorate these disorders. The objective for this program is to develop new hardware and modeling tools to better discriminate the relationship between human behavioral expression and neural function and to provide relief through novel devices. These tools will allow for an improved understanding of how the brain regulates behavior and will enable new, disorder-	-	21.500	31.089

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
specific, dynamic neuro-therapies for treating neuropsychiatric and neurological disorders in military personnel. Technologies of interest under this thrust include devices for real-time detection of brain activity during operational tasks, time synchronized acquisition of brain activity and behavior, and statistical models that correlate neural activity with human behavioral expression. ***FY 2015 Plans:*** - Develop tests that activate key brain subnetworks for each functional domain. - Develop computer algorithms/programs to automatically merge elements of multimodal brain activity across time/space. - Create statistical computational models of brain activity and corresponding behavior to support the neurophysiology of new therapeutic systems. - Train decoders on a subset of domains and cross-validate on novel scan, record, and stimulate data. - Develop hardware interface stability, biocompatibility, and motion correction for recording neural activity. - Demonstrate three-dimensional, single-cell-resolution acquisition of real-time brain activity in large volumes of neural tissue. - Submit initial, novel devices for regulatory approval. ***FY 2016 Plans:*** - Develop and apply data co-registration and fusion methods for neural activity, wiring and behavior. - Generate and annotate first intact neural tissue volumes to elucidate microstructure and connections in three dimensions. - Design algorithms for automatic cell identification and optical-signal estimation. - Elucidate neural circuit dynamics using structurally-informed network models. - Refine optical techniques for imaging large volumes of neural tissue. - Expand data curation architecture, databases, and analytical tools to distribute generated data to the neuroscience community. - Develop methods for automatically detecting and removing noise or contamination from datasets. - Deliver a hierarchical computational model of key brain networks that captures features relevant for psychiatric illness and its treatment. - Develop and refine neural state acquisition, classification and control algorithms to support closed-loop control in an implantable neural device. - Characterize neural network plasticity during behavioral training.			
Title: Prosthetic Hand Proprioception & Touch Interfaces (HAPTIX)	-	10.550	18.800
Description: Wounded warriors with amputated limbs get limited benefit from recent advances in prosthetic-limb technology because the user interface for controlling the limb is low-performance and unreliable. Through investments in the DARPA Reliable Neural-Interface Technology (RE-NET) program, novel interface systems have been developed that overcome these issues and are designed to last for the lifetime of the patient. The goal of the Prosthetic Hand Proprioception & Touch Interfaces (HAPTIX) program is to create the first bi-directional (motor & sensory) peripheral nerve implant for controlling and sensing			

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
advanced prosthetic limb systems. With a strong focus on transition, the HAPTIX program will create and transition clinically relevant technology in support of wounded warriors suffering from single or multiple limb loss. ***FY 2015 Plans:*** - Develop and demonstrate advanced algorithms to control prosthetic limbs using signals extracted from commercially available or newly developed electrodes. - Develop and demonstrate micro-stimulation interface technologies that provide reliable signals into the peripheral and/or central nervous system for closed-loop prosthetic control. - Perform safety and efficacy testing of novel implantable interface technology which capture motor control signals and provide electrical sensory stimulation through the peripheral nervous system. - Demonstrate bench-top functionality of next-generation peripheral interface technology. - Develop draft version of outcome metrics for quantifying effects of implantable and external system components on motor function, sensory function, pain, psychological health and quality of life. - Develop unified virtual prosthesis environment to simulate limb motion and forces of interaction during object manipulation. ***FY 2016 Plans:*** - Integrate interface and electronic systems technology for use in human amputees to control and receive intuitive sensory feedback from a prosthetic device. - Demonstrate closed-loop control of a government-furnished virtual prosthesis. - Perform safety and efficacy testing of integrated HAPTIX system to capture motor control signals and provide electrical sensory stimulation through the peripheral nervous system. - Demonstrate in vivo functionality of next-generation HAPTIX peripheral interface technology. - Determine HAPTIX system prosthetic limb technology, complete sensorization, and begin manufacturing of devices. - Implement draft version of outcome metrics for quantifying effects of HAPTIX technology and begin validation studies.			
Title: Performance Optimization in Complex Environments ***Description:*** The Performance Optimization in Complex Environments program focuses on leveraging advances in and integration of sensors, computation, analytics, and medicine to enable optimum human performance in complex environments. Device technology has advanced to the point where human beings can be instrumented with and connected to a broad range of unobtrusive, always-on physiological, cognitive, and contextual sensors and information systems. At the same time, body-area networks, wearable displays, haptics, and other novel forms of human-computer interfaces have advanced enough that convenient real-time multifactor analysis for neurofeedback and biofeedback are within reach. The Performance Optimization in Complex Environments program will focus on developing the necessary models, analytical tools, interfaces, and input-output modalities necessary to integrate these two advancing areas to enable optimal performance in a wide variety of activities from learning and training to specialized tasking, and to mitigate the effects of age, mental impairment, and physical injury, among	-	-	11.800

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
others. Research will also focus on understanding various forms of sensing and actuation to improve outcomes and how biofeedback over time can alter human physiology. Technologies developed through this program will provide a foundation of novel value propositions to the warfighter in terms of individual health, resilience, cognitive and physical effectiveness, and force multiplication. ***FY 2016 Plans:*** - Begin development of new algorithms for sensing and modeling of physiological and cognitive state. - Explore and identify primary sensing methods for reading biological signals. - Begin research on biological interfaces for enabling input-output of information. - Explore and study impact of various actuation mechanisms on physiological state and outcomes.			
Title: Tactical Biomedical Technologies	13.321	12.000	-
Description: The Tactical Biomedical Technologies thrust will develop new approaches to deliver life-saving medical care on the battlefield. Uncontrolled blood loss is the leading cause of preventable death for soldiers on the battlefield. While immediate control of hemorrhage is the most effective strategy for treating combat casualties and saving lives, currently no method, other than surgical intervention, can effectively treat intracavitary bleeding. A focus in this thrust is the co-development of a materials-based agent(s) and delivery mechanism capable of hemostasis and wound control for non-compressible hemorrhage in the abdominal space, regardless of wound geometry or location within that space. This thrust will also investigate non-invasive techniques and equipment to use laser energy to treat intracranial hemorrhage through the skull and tissues in a pre-surgical environment. Finally, in order to address logistical delays associated with delivering necessary therapeutics to the battlefield, this thrust will also develop a pharmacy on demand that will provide a rapid response capability to enable far-forward medical providers the ability to manufacture and produce small molecule drugs and biologics. ***FY 2014 Accomplishments:*** - At laboratory scale, designed continuous flow synthesis steps for the following Active Pharmaceutical Ingredients (APIs): Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine. - Engaged the Food and Drug Administration (FDA) for input on Process Analytical Technologies (PAT) and current Good Manufacturing Process (cGMP) for Diphenhydramine, Diazepam, Lidocaine, Fluoxetine, Ibuprofen, Atropine, and Doxycycline. - Performed in vivo demonstration of transcranial photocoagulation of intracranial vessels in porcine model. - Performed in vivo demonstration of photo-induced vasospasm in intracranial vessels in porcine model. - Designed and developed upstream and downstream components of miniaturized end-to-end manufacturing platform for protein therapeutics using cell-free and cell-based protein translation systems, including integration of protein expression and purification processes. ***FY 2015 Plans:***			

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Develop novel continuous flow crystallizer, miniaturized reactors, and chemically compatible pumps for integration into a compact end-to-end manufacturing platform for the following APIs: Diphenhydramine, Diazepam, Lidocaine, Fluoxetine, Ibuprofen, Atropine, Doxycycline, Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine. - Demonstrate continuous flow synthesis, crystallization, and formulation for Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine, in an integrated manufacturing platform. - Engage the FDA for input on PAT and cGMP for Salbutamol, Ciprofloxacin, Azithromycin, Rufinamide, Etomidate, Nicardipine, and Neostigmine. - Develop novel cell-free protein synthesis techniques using miniaturized bioreactors and/or microfluidics technologies. - Demonstrate end-to-end manufacturing of two protein therapeutics in a miniaturized platform, including the integration of protein expression and purification processes. - Engage the FDA for input on PAT and cGMP for protein therapeutics. - Design end-to-end manufacturing process in a miniaturized and integrated platform for an additional four protein therapeutics. - Test prototype device during in vivo pre-clinical studies for treatment of intracranial hemorrhage using laser energy through skull and tissues, and engage with the FDA on design and execution of these studies to meet FDA requirements.			
Title: Pathogen Defeat	20.678	7.000	-
Description: Pathogens are well known for the high rate of mutation that enables them to escape drug therapies and primary or secondary immune responses. The Pathogen Defeat thrust area will provide capabilities to predict emerging threats and the evolution of resistance of pathogens to medical countermeasures. Pathogen Defeat focuses not only on known pathogens but also newly emerging pathogens and future evolution of mutations in these pathogens, allowing pre-emptive preparation of vaccine and therapy countermeasures. ***FY 2014 Accomplishments:*** - Predicted location of genetic mutation(s) responsible for failure of a monoclonal antibody to neutralize a virus. - Demonstrated that an in vitro drop microfluidics evolution platform can be used to rapidly evolve viruses at the single event level. - Began transition discussions on in vitro evolution platforms to increase preparedness for diseases like seasonal influenza, Dengue, and other emerging human pathogens. - Began development of a hand-held device for rapid identification of microbial organisms, including development of diagnostic panels to be integrated into a modular, single-use microfluidics card. - Explored constraints of pressures (antibodies, anti-virals) on viral evolution and effects on reassortment and recombination. ***FY 2015 Plans:*** - Test predictive capabilities of trajectories to clinical viral isolates in evolution platform. - Elucidate mechanisms to explain viral escape to different pressures. - Rapidly evolve virus strains in avian cells to select vaccine candidates with antigenic similarities.			

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Perform objective field assessment of hand-held devices for microbial and viral pathogens for clinical and environmental testing.			
Title: Military Medical Imaging ***Description:*** The Military Medical Imaging thrust developed medical imaging capabilities to support military missions and operations. The emergence of advanced medical imaging includes newly recognized physical properties of biological tissue, metabolic pathways, or physiological function in order to produce an image of diagnostic utility and performance. The goal of this thrust was to develop new, portable spectroscopic techniques that can provide information for military medical use (e.g., analysis of traumatic brain injury) that is superior to that provided by an MRI. This need is ever increasing as researchers and scientists seek to better understand anatomical, functional, and cellular-level interactions. Finally, this thrust allowed safe, non-invasive to minimally invasive detection of microscopic and functional alterations within tissues and organs of a living organism at early stages of injury. The advanced development of these tools has provided a formidable arsenal of diagnostic tools for warfighter performance and care. ***FY 2014 Accomplishments:*** - Designed and fabricated blazed, stacked, diffractive x-ray optics for integration into a pre-clinical imaging prototype. - Designed and tested imaging and validation protocols for pre-clinical imaging prototype. - Identified candidate approaches for real-time analysis and monitoring of biological activity during performance of behavioral tasks. - Developed electrophysiological methods for simultaneous recording of multiple levels of abstraction in cortical/subcortical targets.	8.000	-	-
Title: Revolutionizing Prosthetics ***Description:*** The goal of this thrust was to radically improve the state of the art for upper limb prosthetics, moving them from crude devices with minimal capabilities to fully integrated and functional limb replacements. Current prosthetic technology generally provides only gross motor functions, with very crude approaches to control. This makes it difficult for wounded soldiers to re-acquire full functionality and return to military service if so desired. The advances required to provide fully functional limb replacements were achieved by an aggressive, milestone-driven program combining the talents of scientists from diverse areas including: medicine, neuroscience, orthopedics, engineering, materials science, control and information theory, mathematics, power, manufacturing, rehabilitation, psychology, and training. The results of this program radically improved the ability of combat amputees to return to normal function. ***FY 2014 Accomplishments:*** - Conducted pre-launch activities of non-invasively controlled prosthetic arm system. - Demonstrated brain control of bilateral prosthetic arms simultaneously.	10.000	-	-

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Incorporated design updates in prosthetic arm systems to improve reliability. - Continued human quadriplegic patient trials demonstrating longevity of cortical control.			
Accomplishments/Planned Programs Subtotals	121.152	112.242	114.262

	FY 2014	FY 2015
Congressional Add: Ebola Response and Preparedness Congressional Add (Emergency Funds) ***FY 2015 Plans:*** This program will speed the development of Ebola antibodies, vaccines, and diagnostics to enable a more rapid response to this outbreak and increase preparedness for response to future epidemics. Planned research builds on earlier investments by DARPA exploring technologies to discover, optimize, and deliver antibodies as a means to provide fast-acting protection against infectious diseases. A key component of this program is not only identifying effective antibodies to treat and prevent disease, but also defining and developing the antibody gene blueprint for transfer and production of vaccines. The Ebola Response and Preparedness Congressional Add is non-OCO emergency funding. - Conduct dose escalation study for encoded Ebola vaccine. - Demonstrate rapid discovery of potent antibodies from human Ebola survivors. - Evaluate protective efficacy of encoded Ebola antibodies in small and/or large animal models. - Test protective efficacy of encoded Ebola vaccine in small and/or large animal models. - Validate cell-free production of nucleic acid-encoded antibody or vaccine formulations.	-	45.000
Congressional Add: Biomedical Congressional Add ***FY 2015 Plans:*** This effort will further the development of restorative products and technologies as alternatives to amputation.	-	2.548
Congressional Adds Subtotals	-	47.548

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

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F. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
Total Program Element	-	370.643	324.407	356.358	-	356.358	364.076	355.357	368.535	368.091	-	-
IT-02: *HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES*	-	66.481	29.800	51.490	-	51.490	58.659	58.379	63.846	58.413	-	-
IT-03: *INFORMATION ASSURANCE AND SURVIVABILITY*	-	172.063	179.947	208.957	-	208.957	240.177	245.501	249.833	254.923	-	-
IT-04: *LANGUAGE TECHNOLOGY*	-	74.332	45.511	60.897	-	60.897	65.240	51.477	54.856	54.755	-	-
IT-05: *CYBER TECHNOLOGY*	-	57.767	69.149	35.014	-	35.014	-	-	-	-	-	-

A. Mission Description and Budget Item Justification

The Information and Communications Technology program element is budgeted in the applied research budget activity because it is directed toward the application of advanced, innovative computing systems and communications technologies.

The High Productivity, High-Performance Responsive Architectures project is developing the necessary computing hardware and the associated software technology base required to support future critical national security needs for computationally-intensive and data-intensive applications. These technologies will lead to new multi-generation product lines of commercially viable, sustainable computing systems for a broad spectrum of scientific and engineering applications; it will include supercomputer, embedded computing systems, and novel design tools for manufacturing of defense systems.

The Information Assurance and Survivability project is developing the core computing and networking technologies required to protect DoD's information, information infrastructure, and mission-critical information systems. The technologies will provide cost-effective security and survivability solutions that enable DoD information systems to operate correctly and continuously even under attack.

The Language Technology project will develop human language technologies to provide critical capabilities for a wide range of national security needs ranging from knowledge management to low-resource language understanding. This project develops technologies to automatically translate, collate, filter, synthesize, summarize, and present relevant information in timely and relevant forms. The Language Technology project is addressing these diverse requirements by developing core language processing technologies and integrating these technologies into operational prototypes suitable for use in the field.

The Cyber Technology project develops technology to increase the security of military information systems and the effectiveness of cyber operations. Over the past decade the DoD has embraced net-centric warfare by integrating people, platforms, weapons, sensors, and decision aids. Adversaries seek to limit this force multiplier

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through cyber attacks intended to degrade, disrupt, or deny military computing, communications, and networking systems. Technologies developed under the Cyber Technology project will ensure DoD net-centric capabilities survive adversary cyber attacks and will enable new cyber-warfighting capabilities.

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	399.597	334.407	339.844	-	339.844
Current President's Budget	370.643	324.407	356.358	-	356.358
Total Adjustments	-28.954	-10.000	16.514	-	16.514
• Congressional General Reductions	-	-			
• Congressional Directed Reductions	-	-10.000			
• Congressional Rescissions	-	-			
• Congressional Adds	-	-			
• Congressional Directed Transfers	-	-			
• Reprogrammings	-17.142	-			
• SBIR/STTR Transfer	-11.812	-			
• TotalOtherAdjustments	-	-	16.514	-	16.514

Change Summary Explanation

FY 2014: Decrease reflects below threshold and omnibus reprogrammings and the SBIR/STTR transfer.

FY 2015: Decrease reflects congressional reduction.

FY 2016: Increase reflects initiation of new start programs in the High-Productivity, High-Performance Responsive Architectures project and expansion of the Low Resource Languages for Emergent Incidents (LORELEI) Technology effort.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-02 / *HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
IT-02: *HIGH PRODUCTIVITY, HIGH-PERFORMANCE RESPONSIVE ARCHITECTURES*	-	66.481	29.800	51.490	-	51.490	58.659	58.379	63.846	58.413	-	-

A. Mission Description and Budget Item Justification

The High Productivity, High-Performance Responsive Architectures project is developing high-productivity, high-performance computer hardware and the associated software technology base required to support future critical national security needs for computationally-intensive and data-intensive applications. These technologies will lead to new multi-generation product lines of commercially viable, sustainable computing systems for a broad spectrum of scientific and engineering applications; it will include both supercomputer and embedded computing systems. One of the major challenges currently facing the DoD is the prohibitively high cost, time, and expertise required to build large complex software systems. Powerful new approaches and tools are needed to enable the rapid and efficient production of new software, including software that can be easily changed to address new requirements and can adjust dynamically to platform and environmental perturbations. The project will ensure accessibility and usability to a wide range of application developers, not just computational science experts.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Power Efficiency Revolution For Embedded Computing Technologies (PERFECT)	41.253	23.800	23.800

Description: The Power Efficiency Revolution For Embedded Computing Technologies (PERFECT) program will provide the technologies and techniques to overcome the power efficiency barriers which currently constrain embedded computing systems capabilities and limit the potential of future embedded systems. The warfighting problem this program will solve is the inability to process future real time data streams within real-world embedded system power constraints. This is a challenge for embedded applications, from Intelligence, Surveillance and Reconnaissance (ISR) systems on unmanned air vehicles through combat and control systems on submarines. The PERFECT program will overcome processing power efficiency limitations by developing approaches including near threshold voltage operation, massive and heterogeneous processing concurrency, new architecture concepts, and hardware and software approaches to address system resiliency, combined with software approaches to effectively utilize resulting system concurrency and data placement to provide the required embedded system processing power efficiency.

FY 2014 Accomplishments:

- Developed an analytical modeling framework for fundamental design trade-off analysis and documentation for local resilience and power optimizations and global optimization methodologies and techniques. Included delivery of initial IBM layered analytical framework addressing concept specification of cross-layer resiliency optimization methodologies, power performance/optimal voltage selection, and throughput performance that developed fundamental trade-off capabilities for power, performance, and

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
reliability for a given embedded system and application space. Included release of improved generation of UC Berkeley Chisel 2.0 hardware construction language for design exploration and generation. - Established algorithmic analysis and design methodologies for power efficient and resilient processing. Included first practical implementation of communication-avoiding rectangular matrix multiplication using a communication-optimal recursive algorithm, outperforming the Intel Math Kernel Library hand-optimized implementation by up to 10x. - Defined power efficient, heterogeneous, highly concurrent conceptual architectural design approaches. Test and verification team evaluation report of results to date confirmed collective capabilities to obtain program goal of 75 GFLOPS/W embedded system performance. The evaluation was based on design concepts for power efficient architecture implementations. - Defined and evaluated the impact of 3D approaches for power efficient processing, including design and simulation of a 3D-stacked Logic-in-Memory (LiM) system architecture to accelerate the processing of sparse matrix data. Simulation results outperform state-of-the-art server and GPU systems by 100x in performance and 1000x in energy efficiency.			
FY 2015 Plans: - Incorporate test chip results - circuit, architecture, communication, power management, 3D - for design optimization and simulation refinement for continuing architectural development efforts. - Develop compiler algorithms supporting communication-avoiding optimization, concepts for optimizing parallel codes and language-based auto-tuning. - Deliver system-level integrated analytical modeling methodology and software analysis toolset for cross-layer, energy-constrained resilience optimization, processor, memory, and energy-reliability trade-offs. - Publically release new hardware description language and modeling/simulation infrastructure incorporating the evaluation and development of algorithms, specializers, hardware architectures, and resiliency techniques.			
FY 2016 Plans: - Identify and select implementation and transition targets and establish collective PERFECT teams technologies to support target requirements. - Extend device models to include different physical device scattering mechanisms including acoustic phonon scattering and the impact of quantum mechanical effects on device level characteristics and provide updated device models and libraries of logic gates and memory bit cells incorporating optimization methodologies for super threshold and near threshold operation. - Complete hardware design evaluations for: low voltage on-chip RAM; adaptive clocking; low-energy signaling; energy-efficient architecture hierarchies; application-specific processing; specialized DRAM architectures; diverse heterogeneous architectures. - Develop the language constructs and compiler technology supporting the implementation of communication avoiding algorithms and the optimizing and managing of processor heterogeneity, concurrency, data locality, and language based autotuning. - Implement modeling and evaluation environment integration combining separate optimization tools for power, communication avoidance, and resiliency to provide detailed trade-off analysis results and insight and demonstrate on a range of (1) ISR			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
kernels (2) PERFECT hardware targets, and (3) problem instance sizes to support 20X power savings incorporating resiliency requirements relative to classical compilers on representative PERFECT hardware architectures.			
Title: Complexity Management Hardware*	-	6.000	12.190
Description: *Formerly Cortical Processor The battlefield of the future will have more data generators and sensors to provide information required for successful combat operations. With networked sensors, the variety and complexity of the information streams will be even further extended. In this project, we will develop silicon designs which help alleviate the complexity inherent in next generation systems. These systems will have increasingly large data sets generated by their own multidomain sensors (such as RF and Electro-Optical/Infrared (EO/IR) payloads) as well as potentially new inputs from external sensors. With current programming approaches, there are laborious coding requirements needed to accommodate new data streams. Additionally, the context provided by these data sets is ever changing, and it is imperative for the integrated electronics to adapt to new information without a prolonged programming cycle. Providing contextual cues for processing of data streams will alleviate the fusion challenges that are currently faced, and which stress networked battlefield systems. As opposed to the intuition and future-proofing that is required at the programming stage of a current system, the silicon circuit of the future will be able to use contextual cues to adapt accordingly to new information as it is provided. The applied research aspects of this program will look at the circuit design which can exploit the algorithms showing benefit for complexity management. This will entail various sparse versus dense data manipulations with hardware implementations catered to both types of data. The program will show hardware implementations that gracefully handle multiple data streams and limit the programming burden for a complex scenario. Basic research for the program is budgeted in PE 0601101E, Project CCS-02. ***FY 2015 Plans:*** - Design complexity management processor algorithm and benchmark tests for object recognition in still images and action recognition in video. - Demonstrate critical features of algorithm including ability to learn and adapt while operating. - Quantify impact of using low precision, sparse network connectivity on accuracy of results. ***FY 2016 Plans:*** - Design transistor level circuits implementing the complexity management algorithms. - Demonstrate the ability to manage multiple data streams with interlaced information.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Create initial hardware verification of concepts for both sparse and hardware demonstrations.			
Title: Scalable Optical Nodes for Networked Edge Traversal (SONNET) ***Description:*** Graph analytics on large data sets is currently performed on leadership-class supercomputers that are designed for other purposes. These machines are required because they have the memory capacity required for large graph problems, but the demand on the processors is low, resulting in extremely low compute efficiency. Computationally, graph analysis is characterized by many short, random accesses to memory which is inefficient on current systems that are optimized for regular, predictable access. The SONNET program will build a silicon photonics-based graph processor that will perform graph analysis on Terabytes (TBs) of data with performance comparable to peta-scale supercomputers in a significantly smaller size, weight, and power (SWAP) envelope. SONNET will optimize the design of the graph processor by co-designing processor and photonic hardware, and the computer and network architectures to exploit the high bandwidth provided by silicon photonics. SONNET will demonstrate a scalable, power efficient prototype of such a graph processor and quantify performance for DoD-relevant applications. The performance, efficiency, and size will be transformational for big data analytics and enable real-time analysis on dynamic graphs in the fields of cyber security, threat detection, and numerous others. This program will explore the efficient processing of local information using stacked memory and integrated circuits specially made for specific tasks, as well as the efficient transfer of data between local information processors. The SONNET program will optimize the design of a graph processor and design and demonstrate high performance processor cores to accelerate graph primitives and photonic hardware required for high bandwidth, low diameter photonic networks. The program will design and evaluate a Graph processor capable of analyzing large data sets relevant to future DoD requirements. This program has advanced technology development efforts funded in PE 0603760E, CCC-02. ***FY 2016 Plans:*** - Identify common graph primitives that would accelerate the execution of DoD-specific applications. - Explore the applications benefitting from the unique architecture and whether unique hardware design allows for processors for unique military applications. - Design corresponding hardware, e.g. processor cores, to optimize performance for high bandwidth photonic networks. - Design algorithms to execute DoD problems on a SONNET system and estimate system performance.	-	-	3.500
Title: Electronic Globalization ***Description:*** Approximately 66% of all installed semiconductor wafer capacity is in Asia. This creates a significant risk for the DoD as off-shore manufacturing of microelectronic components could introduce various vulnerabilities to DoD systems that utilize these non-U.S. fabricated electronic components. As the DoD is faced with this globalization reality, it is essential to prevent	-	-	12.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
potential consequences such as reverse engineering, theft of U.S. intellectual property, and non-authorized use of these electronic components in adversary defense systems. New applied research technology enablement will be developed in the Electronics Globalization program to provide the desired responses such as special chip packaging, on-board infrastructures, process modifications, and the use of Supply Chain Hardware Intercepts for Electronics Defense (SHIELD)-monitor dielet. Applied research will focus on the engineering of unique devices and circuit technologies. Concepts and design flows which enable trust in an untrusted environment will be developed and applied. Basic research for the program is budgeted in PE 0601101E, Project ES-01. ***FY 2016 Plans:*** - Develop a specific CONOP using the proposed structure, and identifying key enablers needed to realize it. - Model designs such as encryption engines used to enable authorized chip operation. - Create and model process module modifications for a standard fab gate recipe that result in desired behaviors. - Demonstrate proof-of-concept of the ability of SHIELD-like devices to selectively authorize chip operation. - Complete a high level design of piggyback chips which can monitor and alter instruction execution of the host component.			
Title: Instant Foundry Adaptive Through Bits (iFAB) ***Description:*** Instant Foundry Adaptive Through Bits (iFAB), provided the groundwork for the development of a foundry-style manufacturing capability--taking as input a verified system design--capable of rapid reconfiguration to accommodate a wide range of design variability and specifically targeted at the fabrication of military ground vehicles. The iFAB vision was to move away from wrapping a capital-intensive manufacturing facility around a single defense product, and toward the creation of a flexible, programmable, potentially distributed production capability able to accommodate a wide range of systems and system variants with extremely rapid reconfiguration timescales. The specific goals of the iFAB program were to rapidly design and configure manufacturing capabilities to support the fabrication of a wide array of infantry fighting vehicle models and variants. Once a given design was developed and verified, iFAB took the formal design representation and automatically configured a digitally-programmable manufacturing facility, including the selection of participating manufacturing facilities and equipment, the sequencing of the product flow and production steps, and the generation of computer-numerically-controlled (CNC) machine instruction sets as well as human instructions and training modules. iFAB was mostly an information architecture. Only the final assembly capability needed to be co-located under a single roof in anything resembling a conventional fabrication facility; the rest of iFAB could be geographically distributed and can extend across corporate and industrial boundaries, united only by a common model architecture and certain rules of behavior and business practices. The final assembly node of the iFAB Foundry was the Joint Manufacturing and Technology Center (JMTC) at the Rock Island Arsenal (RIA).	9.734	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
FY 2014 Accomplishments: - Completed the manufacture and assembly of the winning drivetrain and mobility subsystem design from the first FANG Challenge. - Provided manufacturability feedback to the META design process in support of the tool validation testing. - Transitioned iFAB software tool suite and associated technology to the Digital Manufacturing and Design Innovation Institute (DMDII) through the co-funded research and formal technology transition activities for industry use. - Transitioned all physical infrastructure for the iFAB Foundry final assembly node at RIA to JMTC.			
Title: META ***Description:*** The goal of the META program was to develop novel design flows, tools, and processes to enable a significant improvement in the ability to design complex defense systems that could be verified by virtual testing. The program sought to develop a design representation from which system designs can quickly be assembled and their correctness verified with a high degree of certainty. Such a "fab-less" design approach was complemented by a foundry-style manufacturing capability, consisting of a factory capable of rapid reconfiguration between a large number of products and product variants through bitstream re-programmability, with minimal or no resultant learning curve effects. Together, the fab-less design and foundry-style manufacturing capability was anticipated to yield substantial---by a factor of five ---compression in the time to develop and field complex defense and aerospace systems. ***FY 2014 Accomplishments:*** - Concluded expanded development of META tool suite to include qualitative and relational abstraction modeling, probabilistic certificate of correctness calculations, complexity metric evaluation, non-linear Partial Differential Equation (PDE) analysis, and cyber design evaluation. - Conducted preliminary developmental Beta testing and integrated demonstration testing for the expanded META tool suite including expanded capability features. - Conducted META tool transition activity to commercial Product Lifecycle Management (PLM) tool suites. - Transitioned META software tool suite and associated technology to the Digital Manufacturing and Design Innovation Institute (DMDII) through the use of co-funded research and formal technology transition activities for industry use. - Further expanded META Software tool suite accessibility by developing a web-based solution for the Generic Modeling Environment (GME).	15.494	-	-
Accomplishments/Planned Programs Subtotals	66.481	29.800	51.490

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C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
IT-03: *INFORMATION ASSURANCE AND SURVIVABILITY*	-	172.063	179.947	208.957	-	208.957	240.177	245.501	249.833	254.923	-	-

A. Mission Description and Budget Item Justification

The Information Assurance and Survivability project is developing the core computing and networking technologies required to protect DoD's information, information infrastructure, and mission-critical information systems. The technologies will provide cost-effective security and survivability solutions that enable DoD information systems to operate correctly and continuously even under attack. Technologies developed under this project will benefit other projects within this program element as well as projects in the Command, Control, and Communications program element (PE 0603760E), the Network-Centric Warfare Technology program element (PE 0603766E), the Sensor Technology program element (PE 0603767E), and other projects that require secure, survivable, network-centric information systems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: High Assurance Cyber Military Systems	23.889	24.000	34.500

Description: The High Assurance Cyber Military Systems program will develop and demonstrate technologies to secure mission-critical embedded computing systems. The DoD is making increasing use of networked computing in systems such as military vehicles, weapon systems, ground sensors, smartphones, personal digital assistants, and other communication devices. This dependence makes it critically important that the embedded operating system provides high levels of inherent assurance. This operating system must also integrate the computational, physical, and networking elements of the system while running on a processor with very limited size, weight, and power. Consequently, it can only devote a limited share of its computational resources to security while satisfying hard real-time constraints. Recent advances in program synthesis, formal verification techniques, low-level and domain-specific programming languages, and operating systems mean that fully verified operating systems for embedded devices may be within reach at reasonable costs. The program will develop, mature, and integrate these technologies to produce an embedded computing platform that provides a high level of assurance for mission-critical military applications.

FY 2014 Accomplishments:

- Demonstrated compositionality, which is the ability to construct high assurance systems out of high assurance components.
- Extended the core high-assurance embedded operating system with additional functionality, including automatically generated device drivers and communication protocols.
- Automatically synthesized correct-by-construction control systems from high-level specifications.

FY 2015 Plans:

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Formally verify full functional correctness for the extended core operating system and the automatically synthesized control systems for selected vehicles. - Demonstrate required security properties that follow from correctness for the extended core operating system and the automatically synthesized control systems. - Perform static and dynamic assessments after modifications are made on militarily-relevant vehicles to evaluate the effectiveness of the synthesis and formal methods tools. ***FY 2016 Plans:*** - Apply an architecture-based approach to high-assurance system development to develop a large fraction of the software for a two-processor open-source quadcopter, a helicopter, an unmanned ground vehicle, and an American-built car. - Demonstrate machine-tracked assurance cases for at least six system-wide security properties on targeted vehicles. - Evaluate the effectiveness of approaches by having a red team conduct penetration-testing exercises on the targeted vehicles. - Increase the level of automation of proof generation in theorem provers.			
Title: Vetting Commodity Computing Systems for the DoD (VET) ***Description:*** The Vetting Commodity Computing Systems for the DoD (VET) program will develop tools and methods to uncover backdoors and other hidden malicious functionality in the software and firmware on commodity IT devices. The international supply chain that produces the computer workstations, routers, printers, and mobile devices on which DoD depends provides many opportunities for our adversaries to insert hidden malicious functionality. VET technologies will also enable the detection of software and firmware defects and vulnerabilities that can facilitate adversary attack. ***FY 2014 Accomplishments:*** - Developed relevant application programming interfaces and defined formal semantics for the programming languages to be analyzed. - Produced initial prototype attack scenario generation, program analysis, and diagnostic tools. - Produced initial set of challenge programs for use in a competitive evaluation. - Performed a competitive engagement between research and adversarial challenge performers to produce measurements of research progress against program metrics. ***FY 2015 Plans:*** - Improve the effectiveness of prototype tools, in particular by reducing the rates of false alarms and missed detections, through further competitive engagements. - Expand the set of challenge programs to explore more complex forms of malicious hidden functionality including race conditions, information leakage, and defective encryption.	17.954	21.760	30.325

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Replace initial experimental platforms with more complex devices that are more operationally representative. ***FY 2016 Plans:*** - Use measurements against the program metrics, probabilities of false and missed detection and human analysis time, to identify the new techniques that are likely candidates for integration into an end-to-end DoD vetting application. - Initiate development of an integrated vetting application that incorporates the most promising new techniques and scales to problems of operationally relevant size. - Conduct an integrated end-to-end software/firmware-vetting technology demonstration relevant to potential transition partners.			
Title: Supply Chain Hardware Intercepts for Electronics Defense (SHIELD) ***Description:*** Counterfeit electronic parts are becoming ubiquitous, and pose a threat to the integrity and reliability of DoD systems. Detection of counterfeit components by current means is expensive, time-consuming, and of limited effectiveness. Maintaining complete control of the supply chain using administrative controls incurs substantial costs and has limitations. Current methods of detection involve a wide variety of techniques ranging from functional testing to physical inspections which may still miss certain classes of counterfeits. There have also been attempts by the semiconductor market to protect electronic components through the use of technology embedded in the component or its packaging. However, most methods are specific to a manufacturer's component and as such address only those issues deemed critical to that manufacturer. Some methods can be circumvented, or require slow, expensive, off-site forensic analysis to verify authenticity. The Supply Chain Hardware Intercepts for Electronics Defense (SHIELD) program, leveraging and expanding on previous activities in the IRIS program, will develop a technology capable of confirming, at any time, the authenticity of once-trusted parts, even after they have transited a complex global supply chain. SHIELD will prevent counterfeit component substitution by incorporating a small, inexpensive additional silicon chip ("dielet") within the Integrated Circuit (IC) package. The dielet will provide a unique and encrypted ID as well as anti-tamper features. The microscopic-size dielet embedded in the electronic component packaging will be inductively powered and scanned by an authentication induction coil brought into very close proximity to the packaged chip, thus allowing for verification of chip identity. ***FY 2014 Accomplishments:*** - Defined dielet power consumption and transaction timing specifications. - Defined physical form factor for dielet. - Defined concept of operation for dielet to server communications. - Selected target encryption standard for dielet. ***FY 2015 Plans:*** - Develop behavioral models for SHIELD dielet performance	5.000	17.250	27.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Establish a power budget for all dielet electronics. - Define server communication protocols, encryption scheme, and network architectures. - Develop proof of concept for sensor, power and communications technologies. - Design surrogate dielet for package tests. - Define process modifications needed to accommodate SHIELD insertions. - Develop technologies to allow secure key and ID storage and prevent tampering with the dielet. - Design a compact encryption engine that enables a very small, low power, and low-cost dielet. - Simulate and prototype dielet package-insertion techniques for placing SHIELD dielet on product. ***FY 2016 Plans:*** - Build prototype hardware. - Develop infrastructure needed to execute SHIELD concept of operations. - Design and build network appliance needed for remote interrogation of components.			
Title: Active Cyber Defense (ACD)	12.500	13.828	13.914
Description: The Active Cyber Defense (ACD) program will enable DoD cyber operators to fully leverage our inherent home field advantage when defending the DoD cyber battlespace. In the cyber environment, defenders have detailed knowledge of, and unlimited access to, the system resources that attackers wish to gain. The ACD program will exploit emerging technologies to facilitate the conduct of defensive operations that involve immediate and direct engagement between DoD cyber operators and sophisticated cyber adversaries. Through these active engagements, DoD cyber defenders will be able to more readily disrupt, counter, and neutralize adversary cyber tradecraft in real time. Moreover, ACD-facilitated operations should cause adversaries to be more cautious and increase their work factor by limiting success from their efforts. ***FY 2014 Accomplishments:*** - Developed techniques for countering adversary cyber tradecraft and implemented early prototype software applications. - Developed detailed system designs and design documentation. - Finalized test plans and performed initial evaluations of active cyber defense prototypes in risk reduction assessments. - Provided capabilities to support exercises with transition partners and to perform preliminary operational assessments of technologies. ***FY 2015 Plans:*** - Complete development of system components. - Begin integration of technologies into complete prototype platforms. - Test integrated capabilities. ***FY 2016 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Complete integration of system platforms and demonstrate capabilities to transition partners. - Perform final test and evaluation of integrated capabilities and obtain approval for operational deployment. - Support initial operational fielding of capability to facilitate transition to DoD cyber operators.			
Title: Mission-oriented Resilient Clouds (MRC)	21.571	15.892	14.627
Description: The Mission-oriented Resilient Clouds (MRC) program will create technologies to enable cloud computing systems to survive and operate through cyber attacks. Vulnerabilities found in current standalone and networked systems can be amplified in cloud computing environments. MRC will address this risk by creating advanced network protocols and new approaches to computing in potentially compromised distributed environments. Particular attention will be focused on adapting defenses and allocating resources dynamically in response to attacks and compromises. MRC will create new approaches to measuring trust, reaching consensus in compromised environments, and allocating resources in response to current threats and computational requirements. MRC will develop new verification and control techniques for networks embedded in clouds that must function reliably in complex adversarial environments. ***FY 2014 Accomplishments:*** - Produced a cloud task allocation system that maximizes mission effectiveness in the context of current system loads without significantly increasing hardware costs. - Implemented and evaluated a packet-level monitoring tool that enables flexible, on-the-fly path analysis for network troubleshooting and attack detection. - Validated and deployed an intrusion-tolerant overlay network for cloud monitoring and control. - Transitioned a minimalist library microkernel into open source and commercial hypervisor products. - Evaluated a network path diversity research product for potential transition into USPACOM distributed computing environments. ***FY 2015 Plans:*** - Demonstrate automated construction of diverse, redundant network flow paths that maximize communication resilience in clouds. - Evaluate the scalability and resilience of a high-assurance cloud computing application development library in terms of number of concurrent replicas supported and volume of data handled. - Develop and demonstrate hardened network services through fine-grained memory access controls that determine what valid memory addresses are read or written to by each instruction in a program. - Insert MRC technologies into USPACOM distributed computing environments. - Evaluate technologies in Defense Information Systems Agency (DISA) testbeds to facilitate transitions into DoD clouds. ***FY 2016 Plans:*** - Demonstrate correct, disruption-free upgrading of software defined networking controllers in live networks.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Complete transition of one or more technologies into operational use by USPACOM and DISA.			
Title: Edge-Directed Cyber Technologies for Reliable Mission Communication (EdgeCT)*	-	11.000	22.000
Description: *Previously Secure Distributed Dynamic Computing (SDDC) funded in PE 0603766E, Project NET-01 The Edge-Directed Cyber Technologies for Reliable Mission Communication (EdgeCT) program will enable reliable communications for military forces that operate in disrupted/disadvantaged, intermittent, high-latency environments. The program will create algorithms and software prototypes for use exclusively at the network edge, specifically, on end hosts and/or on proxy servers (middleboxes) fronting groups of such end hosts within a user enclave. EdgeCT systems will sense and respond rapidly to network failures and attacks by dynamically adapting protocols utilized to exchange packets among these hosts, thereby implementing work-arounds (fight-through strategies) that restore networked communication. This will enable highly reliable networked communication for the military in the face of a wide variety of common network failure modes as well as cyber attacks against network infrastructure. EdgeCT technologies will be developed in collaboration with and transitioned to operational commands. ***FY 2015 Plans:*** - Develop a host-based architecture for reliable communications in disrupted/disadvantaged, intermittent, high-latency military environments. - Develop techniques to sense and respond rapidly to network failures and attacks by dynamically adapting protocols utilized to exchange packets among hosts. - Explore modes of user interaction and system concepts of operation with one or more operational commands. ***FY 2016 Plans:*** - Initiate development of software prototypes suitable for laboratory experimentation with operational commands. - Develop work-arounds (fight-through strategies) that rapidly restore networked communication in the face of a wide variety of common network failure modes as well as cyber attacks against network infrastructure. - Bring software prototypes to an initial field experiment in collaboration with an operational command.			
Title: Cyber Fault-tolerant Attack Recovery (CFAR)	-	10.000	20.149
Description: Building upon previous work in the Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH) program, the Cyber Fault-tolerant Attack Recovery (CFAR) program will develop novel architectures to achieve cyber fault-tolerance with commodity computing technologies. Current approaches to handling cyber-induced faults in mission-critical systems are inadequate, as perimeter defenses wrapped around vulnerable monocultures do not scale, while zero-day exploits evade signature-based defenses. The proliferation of processing cores in multi-core central processing units provides the opportunity to adapt fault-tolerant architectures proven in aerospace applications to mission-critical, embedded, and real-time computing			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
systems. The CFAR program will combine techniques for detecting differences across functionally replicated systems with novel variants that guarantee differences in behavior under attack. The resulting CFAR-enabled computing systems will quickly detect deviations in processing elements at attack onset and rapidly reboot to restore affected services. ***FY 2015 Plans:*** - Formulate novel architectures that achieve cyber fault-tolerance with commodity computing technologies without requiring changes to the system concept of operations. - Develop techniques for detecting differences across functionally replicated systems. - Develop novel variants that guarantee differences in behavior under attack. ***FY 2016 Plans:*** - Demonstrate functionally replicated systems and novel variants that provide performance close to optimal and exhibit sufficient variability to guarantee differences in behavior under attack. - Implement and test techniques for quickly detecting differences across replicated systems. - Implement and evaluate alternative architectures for achieving cyber fault-tolerance for mission-critical military applications with commodity computing technologies. - Work with potential transition sponsors to evaluate military computing systems as candidates for technology refresh with CFAR technologies.			
Title: Adaptable Information Access and Control (AIAC)	-	7.093	17.600
Description: The Adaptable Information Access and Control (AIAC) program will create the capability to dynamically, flexibly, and securely share highly selective information across enterprise boundaries. In the civilian sphere, there is a recognized need for technologies that limit the sharing of information between commercial entities and U.S. government agencies to the greatest extent possible consistent with national security requirements. Similarly, the U.S. military is increasingly involved in humanitarian operations that require highly selective sharing of data with a heterogeneous mix of allies, coalition partners, and other stakeholders. AIAC will create confidentiality, privacy, multi-level security, discretionary access control, and policy engine technologies to allow tailored access to specific data and analytic results but not an entire database/file system/corpus. AIAC is timely due to recent progress on cryptographic techniques such as homomorphic encryption, secure multiparty computation, and differential privacy. Additional technologies that will be developed and incorporated include automated policy-driven releasability assessment and redaction, tactical obfuscation, and time-limited-access controls. The program will address the diverse and stringent legal and ethical requirements related to security, privacy, authentication, authorization, auditing, monitoring, access, and control encountered in both civilian and military environments. To facilitate deployment, AIAC technologies will be designed to work with the virtualization, cloud computing, and software-defined networking technologies now widely used in both civilian and military environments.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
FY 2015 Plans: - Formulate access control schemes appropriate for diverse civilian, intelligence, law enforcement, and coalition use cases with particular focus on privacy-preserving analytics. - Architect an access control policy engine for seamless interoperability with common computing and networking infrastructure software. - Create technologies for confidentiality, privacy, multi-level security, discretionary access controls, automated policy-driven releasability assessment and redaction, tactical obfuscation, computing on encrypted data, and time-limited-access controls. ***FY 2016 Plans:*** - Implement access control software prototypes with flexibility adequate to support diverse civilian, intelligence, law enforcement, and coalition use cases and with scalability adequate for big data applications. - Develop an access control policy engine and demonstrate interoperability with common cloud computing and software-defined networking infrastructure and services as appropriate. - Evaluate and refine technologies for confidentiality, privacy, multi-level security, discretionary access controls, automated policy-driven releasability assessment and redaction, tactical obfuscation, computing on encrypted data, and time-limited-access controls.			
Title: Protecting Cyber Physical Infrastructure (PCPI) ***Description:*** * Formerly Protecting Cyber Physical Systems (PCPS) The Protecting Cyber Physical Infrastructure (PCPI) program will create new technologies for ensuring the availability and integrity of critical U.S. cyber-physical infrastructure. The near-ubiquitous use of computers to monitor and control U.S. civilian and military critical infrastructure and the dependence of our society on electric power, clean water, waste processing, petroleum refining, chemical production, and other utilities/industries make this a national security issue. PCPI will develop technologies to monitor heterogeneous distributed control system networks, detect anomalies that require rapid assessment, and mitigate sensor spoofing and denial of service attacks. Hardware-in-the-loop simulation techniques will be developed to enable the discovery of emergent vulnerabilities and the development and optimization of mitigation strategies. This will include understanding the potential role of electric power markets in propagating or damping power grid anomalies. PCPI technologies will transition to military installations and commercial industry. ***FY 2015 Plans:*** - Create a hardware-in-the-loop simulation capability to enable the discovery of emergent vulnerabilities and the development and optimization of mitigation strategies.	-	7.525	17.513

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Formulate resilient architectures for real-time monitoring, analysis, and assessment of distributed industrial control systems and physical infrastructure. - Investigate rapid re-provisioning techniques to quickly re-deploy firmware and operating system images to restore compromised devices back to a pristine, known state of operation. ***FY 2016 Plans:*** - Develop technologies to monitor heterogeneous distributed industrial control system networks, detect anomalies that require rapid assessment, and mitigate sensor spoofing and denial of service attacks. - Extend simulation capabilities to understand the potential role of electric power markets in propagating or damping power grid anomalies. - Develop techniques that use organic sensors, remote instrumentation, and other sources of cyber situation awareness information to continuously optimize cyber defenses. - Explore defensive measures/counter-measures that can mitigate/thwart a coordinated cyber attack on national critical infrastructure.			
Title: Cyber Grand Challenge (CGC) ***Description:*** The Cyber Grand Challenge (CGC) program will create automated defenses that can identify and respond to cyber attacks more rapidly than human operators. CGC technology will monitor defended software and networks during operations, reason about flawed software, formulate effective defenses, and deploy defenses automatically. Technologies to be developed and integrated may include anomaly detection, Monte Carlo input generation, case-based reasoning, heuristics, game theory, and stochastic optimization. The CGC capability is needed because highly-scripted, distributed cyber attacks exhibit speed, complexity, and scale that exceed the capability of human cyber defenders to respond in a timely manner. DARPA will incentivize competition through a Grand Challenge in which CGC technologies compete head-to-head. Principal funding for this effort is provided in Project IT-05. Additional funding is being provided in IT-03 to enable the creation of the more robust competition infrastructure necessary to accommodate the large number of competitors. ***FY 2015 Plans:*** - Create a robust competition infrastructure as required to accommodate the large number of competitors. ***FY 2016 Plans:*** - Conduct world's first automated computer security contest: Cyber Grand Challenge Final Event. - Release event results as cyber research corpus to measure and challenge future automated cyber capabilities.	-	6.233	11.329
Title: Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH)	19.626	11.182	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Description: The Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH) program will develop cyber security technologies using the mechanisms of biological systems as inspiration for radically re-thinking basic hardware and system designs. Higher level organisms have two distinct immune systems: the innate system is fast and deadly but is only effective against a fixed set of pathogens; the adaptive system is slower, but can learn to recognize novel pathogens. Similarly, CRASH will develop mechanisms at the hardware and operating system level that eliminate known vulnerabilities exploited by attackers. However, because novel attacks will be developed, CRASH will also develop software techniques that allow a computer system to defend itself, to maintain its capabilities, and even heal itself. Finally, biological systems show that diversity is an effective population defense; CRASH will develop techniques that make each computer system appear unique to the attacker and allow each system to change over time. ***FY 2014 Accomplishments:*** - Completed the implementation of three novel, secure processors, developed the associated security extensions to one operating system, and subjected each to independent red-team assessment. - Demonstrated the capability to wrap integrated defense software and protect it from cyber attacks launched by an independent red team. - Demonstrated the ability of two or more complete systems to block, survive, and recover from multiple attacks and automatically repair vulnerabilities. - Developed and implemented multiple technologies for adding diversity to applications and assessed the impacts of these technologies on security and performance. - Automatically produced diverse instantiations of one complete operating system and multiple large applications for multiple operating systems. ***FY 2015 Plans:*** - Deliver a hardened web server and browser that enable the creation of secure web applications from untrusted code. - Demonstrate policy-based application monitoring and hardware-assisted self-healing of multiple applications. - Demonstrate hardware-based detection of malicious software.			
Title: Rapid Software Development using Binary Components (RAPID) ***Description:*** The Rapid Software Development using Binary Components (RAPID) program will develop a system to identify and extract software components for reuse in new applications. The DoD has critical applications that must be ported to future operating systems. In many cases, the application source code is no longer available requiring these applications to continue to run on insecure and outdated operating systems, potentially impacting operations. Advanced technology research for the program is budgeted in PE 0603760E, Project CCC-04.	8.198	10.396	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
FY 2014 Accomplishments: - Fully integrated technologies into a single architecture and standardized interfaces to enable partners to interoperate with the system. - Developed a single user interface that combines technical area views for monitoring system performance with a constructive interface for specifying desired products. ***FY 2015 Plans:*** - Develop new software component reuse capabilities to extend application performance to a wider range of realistic scenarios and enable an expanded concept of operations. - Implement new capabilities in modules designed to interoperate seamlessly with deployed RAPID prototype systems. - Integrate new modules into prototype RAPID systems deployed at transition partner sites and support initial operations.			
Title: Anomaly Detection at Multiple Scales (ADAMS) ***Description:*** The Anomaly Detection at Multiple Scales (ADAMS) program will develop and apply algorithms for detecting anomalous, threat-related behavior of systems, individuals, and groups over hours, days, months, and years. ADAMS will develop flexible, scalable, and highly interactive approaches to extracting actionable information from information system log files, sensors, and other instrumentation. ADAMS will integrate these anomaly detection algorithms to produce adaptable systems for timely insider threat detection. ***FY 2014 Accomplishments:*** - Created the capability to incorporate direct user feedback to improve coverage of threat types. - Developed and implemented technology that is adaptable to a wide variety of organizational structures, workflows, and data sources. - Developed techniques to provide the evidence needed to initiate focused response activities. - Developed two integrated prototype anomaly/threat detection systems suitable for rapid deployment in an operational environment. ***FY 2015 Plans:*** - Develop and implement technology to capture analyst expertise for assessing and explaining detected anomalies and incorporate such user feedback in decision loops for operators without highly specialized computer science knowledge. - Harden prototype and obtain DoD Information Assurance Certification and Accreditation Process approval for use on military networks. - Conduct and evaluate initial prototype in a large scale environment with operational partners.	15.272	7.000	-
Title: Active Authentication	13.100	7.025	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Description: The Active Authentication program will develop more effective user identification and authentication technologies. Current authentication approaches are typically based on long, complex passwords and incorporate no mechanism to verify the user originally authenticated is the user still in control of the session. The Active Authentication program will address these issues by focusing on the unique aspects of the individual (i.e., the cognitive fingerprint) through the use of software-based biometrics that continuously validate the identity of the user. Active Authentication will integrate multiple biometric modalities to create an authentication system that is accurate, robust, and transparent to the user. ***FY 2014 Accomplishments:*** - Demonstrated enhanced authentication using multiple biometrics representing complementary aspects of the individual. - Evaluated the level of confidence that is achievable using multiple advanced authentication mechanisms and quantified the resulting level of security using red teaming and other techniques. - Prototyped an authentication platform suitable for DoD use in collaboration with potential transition sponsors. - Initiated development of multiple authentication biometrics suitable for deployment on mobile hardware for potential use by the DoD. ***FY 2015 Plans:*** - Demonstrate multiple authentication biometrics suitable for deployment on mobile hardware for potential use by the DoD. - Prove flexibility of underlying prototype platform by creating an additional authentication platform suitable for DoD. - Prototype an authentication platform suitable for use on mobile hardware in collaboration with potential transition sponsors.			
Title: Safer Warfighter Computing (SAFER) ***Description:*** The Safer Warfighter Computing (SAFER) program is creating a technology base for assured and trustworthy Internet communications and computation, particularly in untrustworthy and adversarial environments. SAFER creates automated processes and technologies to enable military users to send and receive content on the Internet, utilizing commercially available hardware and software, in ways that avoid efforts to deny, locate, or corrupt communications. SAFER is also developing technology for performing computations on encrypted data without decrypting it first through fully homomorphic encryption and interactive, secure multi-party computation schemes. This will enable, for example, the capability to encrypt queries and compute an encrypted search result without decrypting the query. This technology will advance the capability to run programs on untrusted hardware while keeping programs, data, and results encrypted and confidential. This mitigates the important aspect of supply chain compromise. ***FY 2014 Accomplishments:*** - Improved software performance in fully homomorphic encryption, garbled-circuit secure multiparty computation, and secret-sharing secure multiparty computation, and performed independent benchmarks.	15.150	4.066	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrated an additional two orders of magnitude improvement in the performance of fully homomorphic encryption. - Refined field programmable gate array implementation of fully homomorphic encryption to yield a further order of magnitude performance improvement over optimized software implementation. - Demonstrated safe, encrypted Internet communications application: secure Voice over Internet Protocol (VOIP) teleconferencing. ***FY 2015 Plans:*** - Develop improved decoy routing, parallelized group messaging, dynamic traffic camouflage, and rendezvous strategy technologies. - Further optimize field programmable gate array and software implementations of fully homomorphic encryption to double performance over prior implementations. - Conduct the final independent, adversarial assessment of the effectiveness of technologies to prevent communication localization and detection, including newly developed adversarial techniques.			
Title: Integrated Cyber Analysis System (ICAS) ***Description:*** The Integrated Cyber Analysis System (ICAS) program will develop techniques to automatically discover probes, intrusions, and persistent attacks on enterprise networks. At present, discovering the actions of capable adversaries requires painstaking forensic analysis of numerous system logs by highly skilled security analysts and system administrators. ICAS will develop technologies to facilitate the correlation of interactions and behavior patterns across all system data sources and thereby rapidly uncover aberrant events and detect system compromise. This includes technologies for automatically representing, indexing, and reasoning over diverse, distributed, security-related data and system files. ***FY 2014 Accomplishments:*** - Developed a multi-tiered approach to device identification and information extraction by transcoding Simple Protocol and Resource description framework Query Language (SPARQL). - Developed SQL transcoding support to enable Relational Database Management System (RDBMS) information extraction. - Conducted initial demonstrations of core technologies including automatic indexing of data sources, common language integration, and reasoning across federated databases. ***FY 2015 Plans:*** - Develop and implement algorithms for automatically identifying and quantifying specific security risks on enterprise networks. - Conduct initial technology demonstrations including automatic indexing of data sources, common language integration, and reasoning across federated databases. - Integrate, evaluate, and optimize algorithms via testing against attacks/persistent threats provided by transition partners.	10.000	3.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Complete fully functional beta versions of the applications with operational stability suitable for testing at transition partner locations.			
Title: Logan ***Description:*** The Logan program will provide DoD enhanced capabilities to conduct Computer Network Attack (CNA). Techniques will be developed to disrupt and degrade adversary information systems and network operations, with particular interest in techniques likely to be robust to adversary countermeasure strategies. ***FY 2014 Accomplishments:*** - Automated and tested prototypes in conjunction with transition partner. - Optimized and hardened prototypes and initiated transition. ***FY 2015 Plans:*** - Transition automated prototype system.	8.803	2.697	-
Title: Integrity and Reliability of Integrated CircuitS (IRIS) ***Description:*** Integrated circuits (ICs) are core components of most electronic systems developed for the Department of Defense. However, the DoD consumes a very small percentage of the total IC production in the world. As a result of the globalization of the IC marketplace, much of the advanced IC production has moved to offshore foundries, and these parts make up the majority of ICs used in today's military systems. Without the ability to influence and regulate the off-shore fabrication of ICs, there is a risk that parts acquired for DoD systems may not meet stated specifications for performance and reliability. This risk increases considerably with the proliferation of counterfeit ICs in the marketplace, as well as the potential for the introduction of malicious circuits into a design. The Integrity and Reliability of Integrated CircuitS (IRIS) program developed techniques that will provide electronic system developers the ability to validate the function of digital, analog and mixed-signal ICs non-destructively, given limited data about the chip's detailed design specifications. These techniques included advanced imaging for identification of functional elements in deep sub-micrometer Complementary Metal-Oxide Semiconductor (CMOS) circuits, as well as computational methods to deal with the extremely difficult problem of determining device connectivity. Finally, the IRIS program developed innovative methods to determine the reliability of an IC by testing a limited number of samples. The current understanding of IC aging mechanisms, including negative bias temperature instability (NBTI), hot carrier injection (HCI), time-dependent dielectric breakdown (TDDB) and electromigration (EM) was leveraged to develop unique diagnostic test techniques.	1.000	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
FY 2014 Accomplishments: - Exercised completed methods for non-destructive imaging, circuit extraction and functional derivation. - Demonstrated methods for reliability analysis for improved accuracy, functionality and efficacy. - Combined analysis methods for imaging, circuit extraction and reliability modeling to identify anomalies on an integrated circuit test article, and to determine the impact of those anomalies on the reliability of the test article. - Transitioned technology to the Navy and the Air Force Research Lab for deployment in existing programs to analyze circuits for counterfeit issues. - Completed testing and evaluation of performers and test chips by government virtual lab highlighting advancements in program closeout and gaps to be addressed.			
Accomplishments/Planned Programs Subtotals	172.063	179.947	208.957

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
IT-04: *LANGUAGE TECHNOLOGY*	-	74.332	45.511	60.897	-	60.897	65.240	51.477	54.856	54.755	-	-

A. Mission Description and Budget Item Justification

The Language Technology project will develop human language technologies to provide critical capabilities for a wide range of national security needs ranging from knowledge management to low-resource language understanding. Foreign-language news broadcasts, web-posted content, and foreign-language hard-copy documents could provide insights regarding regional and local events, attitudes and activities, if there was a system that could automatically process large volumes of speech and text in multiple languages obtained through a variety of means. The project develops technologies to automatically translate, collate, filter, synthesize, summarize, and present relevant information in timely and relevant forms. In addition, current U.S. military operations often require warfighters on the ground to understand speech and text in foreign languages for which there may be no available linguists. The Language Technology project is addressing these diverse requirements by developing core language processing technologies and integrating these technologies into operational prototypes suitable for use in the field.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Deep Exploration and Filtering of Text (DEFT)	28.369	28.333	30.223

Description: The Deep Exploration and Filtering of Text (DEFT) program will enable automated extraction, processing, and inference of information from text in operationally relevant application domains. A key DEFT emphasis is to determine explicit and implicit meaning in text through probabilistic inference, anomaly detection, and other techniques. To accomplish this, DEFT will develop and apply formal representations for basic facts, spatial, temporal, and associative relationships, causal and process knowledge, textually entailed information, and derived relationships and correlated actions/events. DEFT inputs may be in English or in a foreign language and sources may be completely free-text or semi-structured reports, messages, documents, or databases. DEFT will extract knowledge at scale for open source intelligence and threat analysis. Planned transition partners include the intelligence community and operational commands.

FY 2014 Accomplishments:

- Developed initial methods and algorithms for reasoning about both explicitly and implicitly expressed opinions and beliefs, for extracting causal knowledge, and for finding implicit meaning based on anomalous usages and disfluencies in a document or set of documents.
- Conducted performance evaluations on data sets related to event representation and inference.
- Expanded capabilities to additional application problems and domains such as target information augmentation in collaboration with end-users.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrated feasibility of deep extraction and filtering for selected end-user applications and transitioned initial sets of algorithms to the intelligence community and a Combatant Command. ***FY 2015 Plans:*** - Develop technology for extracting belief, sentiment, and intent; for representing geo-spatial features and temporal events; and for inference and alerting from a set of documents. - Integrate multiple complementary algorithms into a comprehensive and consistent functional suite to support end-user workflows and problems. - Increase algorithm development focus towards knowledge base representation in preparation for embedding algorithms in workflows to enable reasoning and downstream analysis. - Extend algorithms to additional foreign languages such as Spanish and Chinese. - Conduct performance evaluations on data sets related to event representation, anomaly detection, and knowledge base population. - Transition algorithm suites and conduct effectiveness assessments at end-user sites. - Enlarge the scope of event coverage to include increasingly complex events. ***FY 2016 Plans:*** - Improve algorithm performance on current functions and expand to new functions such as extending currently single-document algorithms to function across documents. - Optimize algorithm coverage and improve performance for foreign languages such as Spanish and Chinese. - Join and optimize combined output of algorithms focused on different tasks such as belief and sentiment extraction, event argument and attribute identification, and relation mapping. - Transition system-level prototype to end-user site for effectiveness assessment. - Refine areas of focus based on results of transition site evaluations and open evaluation performance.			
Title: Robust Automatic Translation of Speech (RATS) ***Description:*** The Robust Automatic Transcription of Speech (RATS) program is developing robust speech processing techniques for conditions in which speech signals are degraded by distortion, reverberation, and/or competing conversation. Robust speech processing technologies enable soldiers to hear or read clear English versions of what is being said in their vicinity, despite a noisy or reverberant environment. Techniques of interest include speech activity detection, language identification, speaker identification, and keyword spotting. RATS technology is being developed and optimized on real world data in conjunction with several operational users. ***FY 2014 Accomplishments:***	4.850	6.178	8.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Evaluated performance showing substantial progress on noisy and degraded speech signals from the program-generated data corpus. - Collected and annotated classified field data for training and testing. - Evaluated technologies on field-collected data and tested the system for in-the-field adaptation. - Obtained real world data from operational users and performed testing on site at the user location. - Established relationships with various DoD and intelligence community agencies as potential transition partners. ***FY 2015 Plans:*** - Develop new methods for field adaptations which include lightly supervised and unsupervised adaptation of the algorithms to new channels and environments. - Develop methods for coping with extraneous signals found in field data. - Develop techniques to significantly reduce the amount of data from hours to minutes for adapting algorithms to new channels. - Produce a software integrated platform with a set of Application Programming Interfaces (APIs) and Graphical User Interfaces (GUIs) to be inserted at DoD and intelligence community partner sites and tested in the working environment of the partners. ***FY 2016 Plans:*** - Develop, integrate and test techniques to deal with multiple speakers and overlapping speaker channels. - Collect and annotate additional field collected data. - Integrate technologies in transition partner platforms, adjusting systems to fit partner needs. - Evaluate technologies on specialized operational scenarios.			
Title: Low Resource Languages for Emergent Incidents (LORELEI)* ***Description:*** *Formerly Foreign Language Rapid Response (FLRR) The Low Resource Languages for Emergent Incidents (LORELEI) program will develop the capability to rapidly construct machine translation and other human language technologies for low-resource foreign languages. The United States military operates globally and frequently encounters low-resource languages, i.e., languages for which few linguists are available and no automated human language technology capability exists. Historically, exploiting foreign language materials required protracted effort, and as a result systems exist only for languages in widespread use and in high demand. The goal of the LORELEI program is to dramatically advance the state of computational linguistics and human language technology to enable rapid, low-cost development of language processing capabilities for low-resource languages. To achieve this LORELEI will eliminate reliance on huge, manually-translated, manually-transcribed, or manually-annotated corpora and instead will leverage language-universal resources, project from related-language resources, and fully exploit a broad range of language-specific resources. These capabilities will be exercised to provide situational awareness based on information from any language, in support of emergent	-	11.000	22.174

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
missions such as humanitarian assistance/disaster relief, terrorist attack response, peacekeeping, and infectious disease response. ***FY 2015 Plans:*** - Develop techniques for quantifying the linguistic similarity of language usage in diverse documents and media. - Develop semantic techniques for identifying the common topics, themes, and sentiment in speech and text in diverse foreign languages. - Explore techniques for optimizing combinations of existing resources to eliminate reliance on large parallel corpora in the context of exploiting foreign language sources in low-resource languages. ***FY 2016 Plans:*** - Develop algorithms to exploit the universal properties of languages when rapidly ramping up for a low-resource language. - Collect, generate, and annotate data for an initial set of resources in typologically representative medium-resource languages. - Create a baseline toolkit to rapidly develop an initial situational awareness capability given a new low-resource language document collection.			
Title: Broad Operational Language Translation (BOLT) ***Description:*** The Broad Operational Language Translation (BOLT) program enabled language processing of informal and dialectal genres. Historically, foreign language translation technology was geared toward formal content, like broadcast media and newswire, but did not address informal or dialectal genres. BOLT developed new approaches to automated language translation, human-machine multimodal dialogue, and language generation and applied these to informal genres such as online discussion groups, messaging, and telephone conversation. While Chinese and dialectal Arabic were the two languages addressed directly in BOLT, techniques developed for these two languages have wide applicability to other languages and dialects. ***FY 2014 Accomplishments:*** - Developed improved algorithms for translating two informal genres of Arabic and Chinese text, online discussion groups and messaging, to enable comprehension of colloquialisms and idiomatic speech and added a third genre, telephone conversation. - Used methods developed for Egyptian dialectal Arabic to create databases, tools, and algorithms for additional Arabic dialects. - Developed dialogue management techniques such as computer-moderated turn-taking to avoid divergence as an approach for improving the performance of bi-directional Arabic-English dialogue systems. - Completed the annotated corpora of Arabic and Chinese informal genre data by adding new dialects and enhanced their utility by incorporating additional annotations.	38.913	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-04 / *LANGUAGE TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Formalized government purpose rights and transitioned software for translating informal genres of Arabic and Chinese to a Combatant Command and the Intelligence Community.			
Title: Multilingual Automatic Document Classification, Analysis and Translation (MADCAT) ***Description:*** The Multilingual Automatic Document Classification, Analysis and Translation (MADCAT) program developed and integrated technology to enable exploitation of foreign language hand-written documents. This technology is crucial to the warfighter, as documents such as notebooks, letters, ledgers, annotated maps, newspapers, newsletters, leaflets, pictures of graffiti, and document images captured in the field may contain extremely important time-sensitive information. The MADCAT program addressed this need by producing devices to convert such captured documents from Arabic into readable English in the field. MADCAT substantially improved applicable technologies, in particular document analysis and optical character recognition/ optical handwriting recognition. MADCAT integrated these improved technologies with translation technology and created prototypes for field trials. ***FY 2014 Accomplishments:*** - Fielded MADCAT to multiple Korean sites as an off-line capability for evaluation and routine use by end users. - Evaluated performance of MADCAT in the end user environment showing substantial progress in machine translation of Korean to English and English to Korean on end user provided documents in exercises conducted on site. - Distributed the MADCAT framework for access to the entire U.S. military on the Korean peninsula via the CENTRIX-K network and demonstrated the system during major annual combined U.S.-Korean Forces exercise Ulchi Freedom Guardian. - Developed and deployed a new machine translation capability enabling model adaptation using onsite data and continued to enhance end user learning and recall capabilities with translation memory capabilities. - Signed an MOU with the U.S. Army Chief of Staff in Korea which establishes responsibilities and commitments for MADCAT technology in Korea.	2.200	-	-
Accomplishments/Planned Programs Subtotals	74.332	45.511	60.897

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	Project (Number/Name) IT-05 / *CYBER TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
IT-05: *CYBER TECHNOLOGY*	-	57.767	69.149	35.014	-	35.014	-	-	-	-	-	-

A. Mission Description and Budget Item Justification

The Cyber Technology project develops technology to increase the security of military information systems and the effectiveness of cyber operations. Over the past decade the DoD has embraced net-centric warfare by integrating people, platforms, weapons, sensors, and decision aids. Adversaries seek to limit this force multiplier through cyber attacks intended to degrade, disrupt, or deny military computing, communications, and networking systems. Technologies developed under the Cyber Technology project will ensure DoD net-centric capabilities survive adversary cyber attacks and will enable new cyber-warfighting capabilities. Promising technologies will transition to system-level projects.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Plan X	35.599	43.419	25.150

Description: The Plan X program will develop technologies to enable comprehensive awareness and understanding of the cyber battlespace as required for visualizing, planning, and executing military cyber warfare operations. This includes intelligence preparation of the cyber battlespace, indications and warning of adversary cyber actions, detection of cyber-attack onset, cyber-attacker identification, and cyber battle damage assessment. Plan X will create new graphical interfaces that enable intuitive visualization of events on hosts and networks to aid in the planning and execution of cyber warfare. Plan X will extend operationally meaningful measures to project quantitatively the collateral damage of executed cyber warfare missions.

FY 2014 Accomplishments:

- Created preliminary end-to-end system prototype that supports efficient network mapping, measurement, and network change detection applications.
- Hosted private cloud infrastructure with automated provisioning of computing resources on a standalone closed network that enables a massively distributed data and event store.
- Developed approaches to host Plan X control plane in a wide variety of network architectures using diverse scalable platforms.
- Designed and implemented first generation prototypes of the commander, planner, and operator views for the graphical user interface.
- Created automated network simulation technology to model the cyber battlespace, generate cyber warfare mission plans, and script cyber warfare missions using a domain specific language for programming at Internet scale.
- Collaborated with operators from Air Force, Navy, Marine Corps, and Army cyber components and U.S. Cyber Command.

FY 2015 Plans:

- Create runtime environment and platforms capable of supporting a large scale user base, massive-scale deployments, resiliency to failures of any system component, and managing high ingest rates.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-05 / *CYBER TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrate cyber battle damage assessment from algorithmically placed vantage points. - Demonstrate military network tactical situational awareness applications and use cases. - Release Plan X 1.0 Alpha system and field test capabilities at military cyber exercises such as Cyber Flag and Red Flag. - Conduct field tests of computer network operations scenario development and training capabilities. - Create technical roadmap for transition to operational environment, including understanding of transition partner networks and integration points. ***FY 2016 Plans:*** - Release Plan X 1.0 Beta system and field test with military transition partners at cyber exercises such as Cyber Flag and Red Flag. - Publish application store software development kit and integrate third party cyber capabilities. - Demonstrate large-scale deployment of the end-to-end system with users and roles running on multiple devices in disparate locations. - Integrate with existing military command and control/intel systems to allow bidirectional flow of data to and from Plan X to provide visualization and insights into the cyber battlespace. - Develop and implement technologies for multi-level security access and use privileges. - Integrate multi-level security access and use privileges and initiate technology transition with USCYBERCOM and Service components.			
Title: Cyber Grand Challenge (CGC) ***Description:*** The Cyber Grand Challenge (CGC) program will create automated defenses that can identify and respond to cyber attacks more rapidly than human operators. CGC technology will monitor defended software and networks during operations, reason about flawed software, formulate effective defenses, and deploy defenses automatically. Technologies to be developed and integrated may include anomaly detection, Monte Carlo input generation, case-based reasoning, heuristics, game theory, and stochastic optimization. The CGC capability is needed because highly-scripted, distributed cyber attacks exhibit speed, complexity, and scale that exceed the capability of human cyber defenders to respond in a timely manner. DARPA will incentivize competition through a Grand Challenge in which CGC technologies compete head-to-head. Additional funding for this effort is provided in Project IT-03. ***FY 2014 Accomplishments:*** - Developed host phase of instrumented competition framework for automated cyber defense. - Initiated development of automated cyber defenders to identify flaws and formulate defenses. - Conducted competitive assessments to identify the most promising technology solutions. ***FY 2015 Plans:***	10.438	16.832	9.864

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-05 / *CYBER TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Extend development of automated cyber defenders to allow real time in situ network defense decision making. - Develop a cyber research corpus using techniques from game theory, other quantitative disciplines, and emergent behavior. - Conduct mid-term qualification evaluation of cyber technologies through competitive challenges. ***FY 2016 Plans:*** - Conduct world's first automated computer security contest: Cyber Grand Challenge Final Event. - Release event results as cyber research corpus to measure and challenge future automated cyber capabilities.			
Title: Crowd Sourced Formal Verification (CSFV) ***Description:*** The Crowd-Sourced Formal Verification (CSFV) program will create technologies that enable crowd-sourced approaches to securing software systems through formal verification. Formal software verification is a rigorous method for proving that software has specified properties, but formal verification does not currently scale to the size of software found in modern weapon systems. CSFV will enable non-specialists to participate productively in the formal verification process by transforming formal verification problems into user-driven simulations that are intuitively understandable. ***FY 2014 Accomplishments:*** - Developed five web-based interactive computer simulations based on mapped high-level software specifications and codes. - Launched and maintained public web site to attract the widest possible base for crowd-sourcing formal verifications. - Applied simulations to large Java and C computer programs consisting of hundreds of thousands of lines of source code. - Mapped solutions as code annotations back into formal verification tools and assessed the effectiveness of these solutions by verifying the absence of errors on the MITRE Common Weakness Enumeration/SANS Institute Top 25 lists. - Refined initial simulations and began design and development of five new simulations for greater verification effectiveness. ***FY 2015 Plans:*** - Complete development of five new simulations. - Refine simulations to make them accessible to a large set of non-specialists. - Augment simulations to handle very large Java and C computer programs consisting of millions of lines of source code. - Enhance public web site to include these new simulations. - Assess effectiveness of the new simulations on the large-sized code targets.	11.730	8.898	-
Accomplishments/Planned Programs Subtotals	57.767	69.149	35.014

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602303E / *INFORMATION & COMMUNICATIONS TECHNOLOGY*	**Project (Number/Name)** IT-05 / *CYBER TECHNOLOGY*

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency											Date: February 2015	
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*					R-1 Program Element (Number/Name) PE 0602304E / *COGNITIVE COMPUTING SYSTEMS*							
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
Total Program Element	-	15.847	-	-	-	-	-	-	-	-	-	-
COG-02: *COGNITIVE COMPUTING*	-	3.503	-	-	-	-	-	-	-	-	-	-
COG-03: *COLLECTIVE COGNITIVE SYSTEMS AND INTERFACES*	-	12.344	-	-	-	-	-	-	-	-	-	-

A. Mission Description and Budget Item Justification

The Cognitive Computing Systems program element was budgeted in the Applied Research budget activity because it developed the next revolution in computing and information processing technology that enabled computational systems to have reasoning and learning capabilities and levels of autonomy far beyond those of today's systems. The ability to reason, learn and adapt raised computing to new levels of capability and powerful new applications.

The Cognitive Computing project developed core technologies that enabled computing and autonomy systems to learn and apply knowledge gained through experience. These technologies led to systems with increased self-reliance and the capacity to operate with reduced programmer and operator intervention. In resource-limited settings, these capabilities made the difference between mission success and mission degradation or failure, increased safety by allowing warfighters to operate systems from greater standoff distances, and reduced staffing requirements by providing greater autonomy.

The Collective Cognitive Systems and Interfaces project dramatically improved warfighter and commander effectiveness and productivity using advanced cognitive approaches that enabled faster, better informed, and more highly coordinated actions than those of our enemies. This was accomplished by developing revolutionary methods that increased our information processing capabilities, enhanced our situational awareness, and enabled more cohesive group action by our forces. Critical technical areas addressed in this project included automated decision support, information sharing, ensured communications, and advanced informatics.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602304E / *COGNITIVE COMPUTING SYSTEMS*

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	16.330	-	-	-	-
Current President's Budget	15.847	-	-	-	-
Total Adjustments	-0.483	-	-	-	-
• Congressional General Reductions	-	-			
• Congressional Directed Reductions	-	-			
• Congressional Rescissions	-	-			
• Congressional Adds	-	-			
• Congressional Directed Transfers	-	-			
• Reprogrammings	-	-			
• SBIR/STTR Transfer	-0.483	-			

Change Summary Explanation

FY 2014: Decrease reflects the SBIR/STTR transfer.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency					Date: February 2015							
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602304E / *COGNITIVE COMPUTING SYSTEMS*				Project (Number/Name) COG-02 / *COGNITIVE COMPUTING*			
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
COG-02: *COGNITIVE COMPUTING*	-	3.503	-	-	-	-	-	-	-	-	-	-

A. Mission Description and Budget Item Justification

The Cognitive Computing project developed core technologies that enabled computing and autonomy systems to learn and apply knowledge gained through experience. These technologies led to systems with increased self-reliance and the capacity to operate with reduced programmer and operator intervention. In resource-limited settings, these capabilities made the difference between mission success and mission degradation or failure, increased safety by allowing warfighters to operate systems from greater standoff distances, and reduced staffing requirements by providing greater autonomy.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Autonomous Robotic Manipulation (ARM)	3.503	-	-
Description: The Autonomous Robotic Manipulation (ARM) program developed advanced robotic technologies that enabled autonomous (unmanned) mobile platforms to manipulate objects without human control or intervention. A key objective was intelligent control of manipulators to independently perform subtasks over a broad range of domains of interest to the warfighter, thereby reducing operator workload, time on target, training time, bandwidth, and hardware complexity. Former manipulation systems had many limitations. For example, while they performed well in certain mission environments, they had yet to demonstrate proficiency and flexibility across multiple mission environments; they required burdensome human interaction and the full attention of the operator; and the time required to complete tasks generally exceeded military users' desires. ARM created manipulators with a high degree of autonomy capable of serving multiple military purposes across a wide variety of application domains to include, but not limited to, counter-improvised explosive devices, countermine, search and rescue, weapons support, checkpoint and access control, explosive ordnance disposal, and combat casualty care (including battlefield extraction). ARM enabled autonomous manipulation systems to surpass the performance level of remote manipulation systems that are controlled directly by a human operator. ***FY 2014 Accomplishments:*** - Developed and demonstrated robust algorithms that locate and identify objects in various real-world scenarios. - Evaluated all performer autonomous algorithms through a series of experiments.			
Accomplishments/Planned Programs Subtotals	3.503	-	-

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602304E / *COGNITIVE COMPUTING SYSTEMS*	**Project (Number/Name)** COG-02 / *COGNITIVE COMPUTING*

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602304E / *COGNITIVE COMPUTING SYSTEMS*	Project (Number/Name) COG-03 / *COLLECTIVE COGNITIVE SYSTEMS AND INTERFACES*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
COG-03: *COLLECTIVE COGNITIVE SYSTEMS AND INTERFACES*	-	12.344	-	-	-	-	-	-	-	-	-	-

A. Mission Description and Budget Item Justification

The Collective Cognitive Systems and Interfaces project dramatically improved warfighter and commander effectiveness and productivity using advanced cognitive approaches that enable faster, better informed, and more highly coordinated actions than those of our enemies. This was accomplished by developing revolutionary methods that increase our information processing capabilities, enhance our situational awareness, and enable more cohesive group action by our forces. Critical technical areas addressed in this project included automated decision support, information sharing, ensured communications, and advanced informatics.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Transformative Apps	12.344	-	-
Description: Transformative Apps created the information infrastructure required to enable mission support and tactical applications (apps) to meet the efficiency, security, and availability requirements for use on mobile military networks. Particularly noteworthy was the development of a new data synchronization architecture between handheld devices and backend computing/ storage nodes. Additionally, appropriate middleware services and libraries were developed to facilitate shared capabilities such as map viewing, apps management, and collection of logs, usage statistics, and user feedback. Apps, together with handhelds and networks, were tested in different training environments as well as in deployed environments. Performance and usage were carefully tracked and user feedback collected to guide rapid enhancement of apps. The effort created a military apps development community by reaching out to non-traditional performers and explored new models for software acquisition based on end-user empowerment. ***FY 2014 Accomplishments:*** - Demonstrated full interoperability across hybrid network topologies in a range of operationally relevant contexts. - Refined decentralized imagery processing and dissemination methods for below-brigade users. - Investigated enhanced counter-IED and situational awareness apps for training and CONUS exercises.			
Accomplishments/Planned Programs Subtotals	12.344	-	-

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602304E / *COGNITIVE COMPUTING SYSTEMS*	**Project (Number/Name)** COG-03 / *COLLECTIVE COGNITIVE SYSTEMS AND INTERFACES*

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602383E / *BIOLOGICAL WARFARE DEFENSE*

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
Total Program Element	-	25.648	43.780	29.265	-	29.265	18.250	14.014	13.469	14.346	-	-
BW-01: *BIOLOGICAL WARFARE DEFENSE*	-	25.648	43.780	29.265	-	29.265	18.250	14.014	13.469	14.346	-	-

A. Mission Description and Budget Item Justification

The Biological Warfare Defense project is budgeted in the Applied Research Budget Activity because its focus is on the underlying technologies associated with the detection, prevention, treatment and remediation of biological, chemical, and radionuclide threats.

Efforts to counter existing and emerging biological, chemical and radiological threats include countermeasures to stop the pathophysiologic processes that occur as a consequence of an attack, host immune response enhancers, medical diagnostics for the most virulent pathogens and their molecular mechanisms, collection of environmental trace constituents to support chemical mapping, tactical and strategic biological, chemical, and radiological sensors, and integrated defense systems. This program also includes development of a unique set of platform technologies and medical countermeasures synthesis that will dramatically decrease the timeline from military threat detection to countermeasure availability.

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	24.537	44.825	52.560	-	52.560
Current President's Budget	25.648	43.780	29.265	-	29.265
Total Adjustments	1.111	-1.045	-23.295	-	-23.295
• Congressional General Reductions	-	-1.045			
• Congressional Directed Reductions	-	-			
• Congressional Rescissions	-	-			
• Congressional Adds	-	-			
• Congressional Directed Transfers	-	-			
• Reprogrammings	1.836	-			
• SBIR/STTR Transfer	-0.725	-			
• TotalOtherAdjustments	-	-	-23.295	-	-23.295

Change Summary Explanation

FY 2014: Increase reflects reprogrammings offset by the SBIR/STTR transfer.
FY 2015: Decrease reflects congressional reduction for Section 8024, FFRDC.
FY 2016: Decrease reflects termination of chemical weapons defense program.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602383E / *BIOLOGICAL WARFARE DEFENSE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Medical Countermeasures	25.648	25.780	10.750

Description: To further develop an expedited medical countermeasure capability, emerging technologies will be integrated to address the safety and efficacy considerations in the risk/benefit package necessary to successfully counter naturally emerging or engineered biological warfare threats and new emerging chemical and radiological threats. These technologies will also be focused on reduction of time, risk, and cost associated with new therapeutic development. For example, this program will develop in vitro tissue constructs (IVTC) that will emulate human response to therapeutic compounds, thereby significantly reducing the cost and time for evaluating safety and efficacy of therapeutics.

FY 2014 Accomplishments:
- Demonstrated that the modular platform can be used to predict the kinetics of metabolism and elimination that test compounds are known to exhibit in human physiological systems.
- Initiated design and construction of additional modules that are compatible with the expanded set of IVTCs and enable the platform to sustain the integrated IVTCs for two weeks.
- Demonstrated that two IVTCs individually responded and reacted to test compounds in a manner consistent with the known effects of those compounds on the corresponding human tissues.
- Demonstrated that a modular arrangement of the expanded set of two IVTCs can be used to predict the kinetics of metabolism and elimination that the test compounds are known to exhibit in human physiological systems.
- Investigated novel radiation dosimeter approach to mitigate exposure.

FY 2015 Plans:
- Demonstrate an expanded set of IVTCs able to reproduce the function of four human physiological systems.
- Demonstrate an automated prototype system for monitoring the health and response of IVTCs to test compounds.
- Design and build additional modules that are compatible with the expanded set of IVTCs and enable the platform to sustain the integrated IVTCs for two weeks.
- Demonstrate that the expanded set of four IVTCs individually respond and react to test compounds in a manner consistent with the known effects of those compounds on the corresponding human tissues.
- Demonstrate that a modular arrangement of the expanded set of four IVTCs can be used to predict the absorption, distribution, metabolism, and elimination that the test compounds are known to exhibit in human physiological systems.

FY 2016 Plans:
- Demonstrate an expanded set of IVTCs able to reproduce the function of seven human physiological systems.
- Design and build additional modules that are compatible with the expanded set of IVTCs and enable the platform to sustain the integrated IVTCs for three weeks.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602383E / *BIOLOGICAL WARFARE DEFENSE*

C. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrate that the expanded set of seven IVTCs individually respond and react to test compounds in a manner consistent with the known effects of those compounds on the corresponding human tissues. - Demonstrate that a modular arrangement of the expanded set of seven IVTCs can be used to predict the absorption, distribution, metabolism, and elimination that the test compounds are known to exhibit in human physiological systems.			
Title: Defense Against Mass Terror Threats ***Description:*** The objective of the Defense Against Mass Terror Threats program is to identify and develop technologies that have the potential to significantly improve U.S. ability to reduce the risk of mass casualties in the wake of a nuclear attack. Challenges in reducing U.S. vulnerability to a nuclear attack include monitoring radiation levels and exposure in urban areas and mitigating the lethal short and long term effects of ionizing radiation. A major goal of this program is to develop new sensors and sensing networks that can economically and reliably provide wide area monitoring of radionuclide signatures. ***FY 2015 Plans:*** - Develop the requirements for a low cost, pervasive detection network for wide area monitoring of radionuclide exposure. - Demonstrate novel manufacturing approaches that can lower the cost of radiation detectors without compromising performance. ***FY 2016 Plans:*** - Develop high performance radiation detectors for wide-area monitoring and implement novel manufacturing approaches for low cost production. - Develop and study concepts-of-operations for wide-area radiation monitoring networks.	-	18.000	18.515
Accomplishments/Planned Programs Subtotals	25.648	43.780	29.265

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

F. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency											Date: February 2015	
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*					R-1 Program Element (Number/Name) PE 0602702E / *TACTICAL TECHNOLOGY*							
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
Total Program Element	-	218.482	299.734	314.582	-	314.582	386.540	432.417	430.814	464.014	-	-
TT-03: *NAVAL WARFARE TECHNOLOGY*	-	41.208	53.001	55.687	-	55.687	75.067	92.879	87.321	110.168	-	-
TT-04: *ADVANCED LAND SYSTEMS TECHNOLOGY*	-	36.957	67.075	54.618	-	54.618	70.355	99.355	84.551	84.355	-	-
TT-06: *ADVANCED TACTICAL TECHNOLOGY*	-	19.582	19.494	15.968	-	15.968	33.200	35.672	39.467	24.443	-	-
TT-07: *AERONAUTICS TECHNOLOGY*	-	44.951	46.961	39.971	-	39.971	44.942	47.361	55.424	42.434	-	-
TT-13: *NETWORK CENTRIC ENABLING TECHNOLOGY*	-	75.784	113.203	148.338	-	148.338	162.976	157.150	164.051	202.614	-	-

A. Mission Description and Budget Item Justification

This program element is budgeted in the Applied Research Budget Activity because it supports the advancement of concepts and technologies to enhance the next generation of tactical systems. The Tactical Technology program element funds a number of projects in the areas of Naval Warfare, Advanced Land Systems, Advanced Tactical Technology, Aeronautics Technology and Network Centric Enabling Technology.

The Naval Warfare Technology project develops advanced technologies for application to a broad range of naval requirements. Enabling and novel technologies include concepts for expanding the envelope of operational naval capabilities such as improved situational awareness over large maritime environments, ship self-defense techniques, novel underwater propulsion modalities, high speed underwater vessels, improved techniques for underwater object detection and discrimination, long endurance unmanned surface vehicles, and high bandwidth communications.

The Advanced Land Systems project is developing technologies for enhancing U.S. military effectiveness and survivability in operations ranging from traditional threats to military operations against irregular forces that can employ disruptive or catastrophic capabilities, or disrupt stabilization operations. The emphasis is on developing affordable technologies that will enhance the military's effectiveness while decreasing the exposure of U.S. or allied forces to enemy fire. This project will also explore novel design technologies for the manufacture of ground vehicles and new tools for systems assessments of emerging DARPA technologies.

The Advanced Tactical Technology project focuses on broad technology areas including: a) compact, efficient, frequency-agile, diode-pumped, solid-state lasers for infrared countermeasures, laser radar, holographic laser sensors, communications, and high-power laser applications; and b) new tactical systems for enhanced air vehicle survivability, precision optics, electronic warfare, and advanced air breathing weapons.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*

Aeronautics Technology efforts will address high payoff opportunities that dramatically reduce costs associated with advanced aeronautical systems and/or provide revolutionary new system capabilities for satisfying current and projected military mission requirements. This includes advanced technology studies of revolutionary propulsion and vehicle concepts, sophisticated fabrication methods, and examination of novel materials for aeronautic system applications.

The Network Centric Enabling Technology project develops network-centric mission applications that integrate information arising from: 1) intelligence networks; 2) open and other external sources; 3) sensors and signal/image processors; and 4) collection platforms and weapon systems. Technical challenges include the need to process huge volumes of diverse, incomplete, and uncertain data streams in tactically-relevant timeframes. The data processing efforts include: conditioning of unstructured data, content analysis, behavioral modeling, pattern-of-life characterization, economic activity analysis, social network analysis, anomaly detection, and visualization. Operational benefits include deeper understanding of the evolving operational environment tailored to the needs of commanders at every echelon. Promising technologies are evaluated in the laboratory and demonstrated in the field to facilitate transition.

B. Program Change Summary ($ in Millions)	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total
Previous President's Budget	218.209	305.484	340.564	-	340.564
Current President's Budget	218.482	299.734	314.582	-	314.582
Total Adjustments	0.273	-5.750	-25.982	-	-25.982
• Congressional General Reductions	-	-			
• Congressional Directed Reductions	-	-10.000			
• Congressional Rescissions	-	-			
• Congressional Adds	-	4.250			
• Congressional Directed Transfers	-	-			
• Reprogrammings	6.724	-			
• SBIR/STTR Transfer	-6.451	-			
• TotalOtherAdjustments	-	-	-25.982	-	-25.982

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2014	FY 2015
Project: TT-03: *NAVAL WARFARE TECHNOLOGY*		
Congressional Add: *Arctic Operations Congressional Add*	-	4.250
Congressional Add Subtotals for Project: TT-03	-	4.250
Congressional Add Totals for all Projects	-	4.250

Change Summary Explanation

FY 2014: Increase reflects reprogrammings offset by the SBIR/STTR transfer.

FY 2015: Decrease reflects congressional adjustments.

Exhibit R-2, RDT&E Budget Item Justification: PB 2016 Defense Advanced Research Projects Agency	Date: February 2015
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*

FY 2016: Decrease reflects completion of the Robotics Challenge program and the transition of the Endurance and Vertical Take-Off and Landing (VTOL) Technology Demonstration programs to Budget Activity 3.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency									Date: February 2015			
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / *TACTICAL TECHNOLOGY*				Project (Number/Name) TT-03 / *NAVAL WARFARE TECHNOLOGY*			
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
TT-03: *NAVAL WARFARE TECHNOLOGY*	-	41.208	53.001	55.687	-	55.687	75.067	92.879	87.321	110.168	-	-

A. Mission Description and Budget Item Justification

The Naval Warfare Technology project develops advanced technologies for application to a broad range of naval requirements. Enabling and novel technologies include concepts for expanding the envelope of operational naval capabilities such as improved situational awareness over large maritime environments, ship self-defense techniques, novel underwater propulsion modalities, vessels for estuary and riverine operations, high speed underwater vessels, improved techniques for underwater object detection and discrimination, long endurance unmanned surface vehicles, and high bandwidth communications.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV)	22.951	19.000	8.000

Description: The Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) program has three primary goals: (1) to build and demonstrate an experimental unmanned vessel with beyond state-of-the-art platform performance based on clean sheet design for unmanned operation, (2) demonstrate the technical viability of operating autonomous unmanned craft at theater or global ranges, from forward operating bases, under a sparse remote supervisory control model, and (3) leverage unique ACTUV characteristics to transition a game changing ASW capability to the Navy. By establishing the premise that a human is never intended to step on board at any point in the operational cycle, ACTUV concepts can take advantage of an unexplored design space that eliminates or modifies conventional manned ship design constraints in order to achieve disproportionate speed, endurance, and payload fraction. The resulting unmanned naval vessels must possess sufficient situational awareness and autonomous behavior capability to operate in full compliance with the rules of the road and maritime law to support safe navigation for operational deployments spanning thousands of miles and months of time. When coupled with innovative sensor technologies, the ACTUV system provides a low cost unmanned system with a fundamentally different operational risk calculus that enables game changing capability to detect and track even the quietest diesel electric submarine threats. Key technical areas include unmanned naval vessel design methodologies, ship system reliability, high fidelity sensor fusion to provide an accurate world model for autonomous operation, novel application of sensors for ASW tracking, and holistic system integration due to unique optimization opportunities of the ACTUV system.

FY 2014 Accomplishments:
- Conducted ACTUV sensor and autonomy testing on surrogate platform.
- Initiated ACTUV prototype vessel construction.
- Signed Memorandum of Agreement with the Office of Naval Research for collaborative extended testing of the ACTUV platform.

FY 2015 Plans:
- Complete construction of prototype vessel.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-03 / *NAVAL WARFARE TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Integrate software and hardware into the ACTUV platform. - Initiate at-sea testing to validate performance of vessel, sensor systems, and autonomy. ***FY 2016 Plans:*** - Continue at-sea testing of the completed ACTUV platform to demonstrate autonomy and baseline performance of ASW sensors. - Begin testing of improved ASW sensors. - Demonstrate improved situational awareness and autonomy capabilities, incorporating advanced above water sensors. - Demonstrate the ability to successfully integrate new mission payloads, including a Mine Counter Measures (MCM) payload.			
Title: Upward Falling Payloads (UFP) ***Description:*** The Upward Falling Payloads (UFP) program will develop forward-deployed unmanned distributed systems that can provide non-lethal effects or situational awareness over large maritime environments. Building upon and complimenting concepts for maritime situational awareness and ISR developed under the DASH program, budgeted in Project PE 0603766E/ NET-02, the UFP approach centers on pre-deploying deep-ocean nodes years in advance in forward operating areas which can be commanded from standoff to launch to the surface. Advances in miniaturized sensors and processors, growth in the variety of unmanned systems, and advances in autonomy and networking all point toward highly capable, yet affordable, distributed systems. However, power and logistics to deliver these systems in a timely manner in forward operating areas limit their utility. The UFP program will remove this barrier to accelerate large-scale unmanned distributed missions. The presumption is that a wider range of technology options and system solutions will emerge when the barriers to deployment are removed. ***FY 2014 Accomplishments:*** - Conducted system trade studies addressing a range of UFP applications leading to conceptual designs. - Conducted analysis to characterize long-range deep-sea communications. - Developed conceptual designs for deep-sea containment and launch. ***FY 2015 Plans:*** - Develop UFP nodes capable of extended survival at full depth. - Demonstrate the launch of a UFP surrogate payload to the surface from full depth. - Initiate development of payload subsystems for sensing, communications, and locating. - Demonstrate payload launch capabilities. - Initiate development of communications subsystems. - Study alternative communication modalities. ***FY 2016 Plans:*** - Complete development of payload subsystems for sensing, communications, and locating.	16.257	14.751	22.000

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-03 / *NAVAL WARFARE TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrate deep-ocean launch of payload prototype to the surface with fully functioning subsystems. - Demonstrate the launch of a dormant UFP surrogate payload. - Complete development of communications subsystems. - Demonstrate long-range communications sufficient to wake up a UFP node. - Initiate integration of communications and UFP nodes.			
Title: Strategic Mobility ***Description:*** The goal of the Strategic Mobility program is to analyze and perform risk reduction on technology solutions which can enable rapid deployment of brigade-- or even division-- sized forces globally in a matter of just days. Initially, the activity will focus on identifying high payoff logistics and deployment technologies, and understanding the deployment and sustainment architectures required to support these technologies. The program will examine increased automation in logistics and distribution operations, new platform technologies for sea-based transportation and prepositioning, and technologies which could enable aerial delivery of forces to the vicinity of an objective area. The Strategic Mobility program will then shift to a focused technology risk reduction activity designed to systematically address the principal risks for the highest payoff technology set. The technologies developed by the program could enable a rapid strategic response capability, with rapid deployment and sustainment of substantial ground combat forces, even to very remote or austere locations. ***FY 2016 Plans:*** - Create time and cost model of brigade level deployment technologies and processes. - Perform refined technology trade studies to identify critical component technology. - Initiate development of select logistics technologies with high military payoff.	-	-	8.000
Title: Multi-Azimuth Defense Fast Intercept Round Engagement System (MAD-FIRES)* ***Description:*** *Previously Medium Caliber Precision Weapons, budgeted under Project TT-04. The Multi-Azimuth Defense Fast Intercept Round Engagement (MAD-FIRES) program will validate the premise that high precision extended range (1-10 km) direct fire medium caliber cannons can trade accuracy for size to provide equal or greater lethality compared to traditional larger and more expensive weapon systems. While MAD-FIRES does focus on the most stressing case; ship self defense against the newest and next generation maneuverable and high speed aerial threats, extending the technology could enable smaller combat fighting vehicles and platforms augmented survivability and lethality against larger, more valuable targets. Lethal direct fire overmatch traditionally required larger cannons and larger vehicles to overcome threat armor systems and defenses. MAD-FIRES will change this paradigm and enable smaller platforms by changing the requirement for maintaining lethality overmatch through accuracy rather than size. ***FY 2014 Accomplishments:***	2.000	12.000	17.687

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-03 / *NAVAL WARFARE TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Conducted systems architecture trades and cost studies. - Initiated design studies of candidate weapons systems. ***FY 2015 Plans:*** - Initiate technology development efforts focusing on guidance, packaging and delivery method. - Conduct end-to-end modeling and simulation of all candidate designs. - Begin detailed subsystem design and plans for later stage risk reduction tests. - Begin examining candidate platforms for out-year live-fire tests. ***FY 2016 Plans:*** - Complete detailed subsystem design. - Complete all subsystem tests. - Coordinate with Navy for integrated tests to include approved representative targets.			
Title: Arctic Operations ***Description:*** The Arctic Operations initiative is focused on developing technology to assure U.S. capability to achieve situational awareness in the Arctic. Due to retreating Arctic ice in the coming decades there is an expectation for increased shipping traffic during the summer months, and increased interest in exploiting natural resources along the Arctic continental shelf. This growth in activity will increase the strategic significance of the region, and will drive the need to ensure stability through effective regional monitoring. The extreme environmental conditions of the Arctic may challenge the effectiveness of conventional technology to provide such monitoring. As such, this program seeks to exploit unique physical attributes and emergent environmental trends in the Arctic to create surprising new capabilities, and will develop technologies for persistent and affordable sensing and communication both above and below the ice to ensure responsive operations and domain awareness. ***FY 2015 Plans:*** - Initiate data collection analysis. - Complete data analysis from recovered data collection systems. - Complete data collection analysis from Navy Ice Experiment (ICEX).	-	3.000	-
Accomplishments/Planned Programs Subtotals	41.208	48.751	55.687

	FY 2014	FY 2015
Congressional Add: Arctic Operations Congressional Add ***FY 2015 Plans:*** - Conduct additional study work on technologies to assure U.S. capability to achieve situational awareness in the Arctic.	-	4.250
Congressional Adds Subtotals	-	4.250

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-03 / *NAVAL WARFARE TECHNOLOGY*

C. Other Program Funding Summary ($ in Millions)

Line Item	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
• ACTUV: *ONR PE 0603758N, Project 02918*	-	2.000	-	-	-	-	-	-	-	-	-
• ACTUV (line 2): *ONR PE 0602123N, Project 0000*	-	-	4.877	-	4.877	-	-	-	-	-	-
• ACTUV (line 3): *ONR PE 0603123N, Project 2912*	-	-	2.123	-	2.123	-	-	-	-	-	-

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / *TACTICAL TECHNOLOGY*	Project (Number/Name) TT-04 / *ADVANCED LAND SYSTEMS TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
TT-04: *ADVANCED LAND SYSTEMS TECHNOLOGY*	-	36.957	67.075	54.618	-	54.618	70.355	99.355	84.551	84.355	-	-

A. Mission Description and Budget Item Justification

This project is developing technologies for enhancing U.S. military effectiveness and survivability in operations ranging from traditional threats to military operations against irregular forces that can employ disruptive or catastrophic capabilities, or disrupt stabilization operations. The emphasis is on developing affordable technologies that will enhance the military's effectiveness while decreasing the exposure of U.S. or allied forces to enemy fire. This project will also explore novel design technologies for the manufacture of ground vehicles and new tools for systems assessments of emerging DARPA technologies.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Ground Experimental Vehicle (GXV)	5.606	24.000	22.000

Description: The goal of the Ground Experimental Vehicle (GXV) program is to investigate ground vehicle technologies that enable crew/vehicle survivability through means other than traditional heavy passive armor solutions. This will be accomplished through research and development of novel ground combat and tactical vehicle technology solutions that demonstrate significantly advanced platform mobility, agility, and survivability. The focus of the GXV program will be on technology development across multiple areas to simultaneously improve military ground vehicle survivability and mobility. Traditionally, survivability and mobility have to be traded against each other due to the reliance on heavy armor. The GXV program seeks to break this trend. Coupled with the development of technologies, the GXV program will define concept vehicles which showcase these developmental technologies. A modeling and simulation effort will also be undertaken to understand the vehicle design trade space for the concept vehicles using the developmental technologies and to illustrate how these vehicles might be used operationally in combat scenarios. Technology development areas are likely to include increasing vehicle tactical mobility, survivability through agility, crew augmentation, and signature management, though other relevant technologies may also be pursued.

FY 2014 Accomplishments:
- Initiated research in GXV technology areas.

FY 2015 Plans:
- Continue GXV technology development efforts.
- Define initial concept vehicles based on emerging technologies.
- Develop parametric models for evaluating military utility of technologies.
- Conduct survivability analysis of individual vehicle concepts.

FY 2016 Plans:
- Continue research, development and integration of the most promising technologies.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-04 / *ADVANCED LAND SYSTEMS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Refine the concept vehicles based on the maturing technologies. - Develop modeling and situation tools to incorporate the advantages of the new technologies into existing campaign simulation tools.			
Title: Squad X ***Description:*** *Formerly Infantry Squad Systems (IS2) The U.S. military achieves overmatch against its adversaries via vehicles in all regimes - land, sea and air; however, this level of overmatch is not enjoyed at the squad to individual dismounted warfighter level. The goal of the Squad X program is to leverage advances in real-time situational awareness and mission command; organic three-dimensional dismount mobility; extended range tracking, targeting, and response; and unmanned mobility and perception in order to create a squad with substantial combat overmatch. The concept of overmatch at the squad level includes increased human stand-off, a smaller force density, and adaptive sensing to allow for responses at multiple scales. Squad X will explore advanced wearable force protection, advanced organic squad level direct and indirect trajectory precision weaponry, and non-kinetic precision capabilities. The end result of the Squad X program is an individual dismount unit outfitted with sensors, weaponry, and supporting technology to achieve one-on-one overmatch as well as the overall integration of unmanned assets alongside the dismounts to create a new Hybrid Squad unit. ***FY 2014 Accomplishments:*** - Initiated CONOPS and systems architecture trade studies in the areas of soldier information interaction, network information management, and unmanned information interaction, engineering and perception as well as sensors, precision effects, and support technology for squad sensing, targeting and response. - Researched technology development efforts in the areas of situational awareness, command and control, and squad effects. ***FY 2015 Plans:*** - Initiate technology development efforts, focusing on enhanced sensor fusion and exploitation, squad collaborative autonomy, and squad organic precision effects. - Complete initial integration trade studies. - Complete technology evaluation and experimentation studies. - Develop virtual, constructive, and live experimentation plan; define modeling and simulation strategy. - Initiate development of virtual test bed. - Conduct Tactical Edge Standards Boards (TESBs) and service-level operational workshops. ***FY 2016 Plans:*** - Conduct virtual and live experiments to obtain a system performance baseline.	5.000	25.500	26.618

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-04 / *ADVANCED LAND SYSTEMS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Refine technology development efforts focusing on enhanced sensor fusion and exploitation, squad collaborative autonomy, and squad organic precision effects. - Implement modeling and simulation environment to allow for an overarching iterative design process and obtain system performance estimations. - Leverage Squad X testbed and simulation environments to iteratively assess developed technology and architecture schemes. - Initiate technology development interfaces focusing on human machine interfaces and the squad common operating picture. - Demonstrate initial individual technology capabilities in technology assessments.			
Title: Mobile Infantry ***Description:*** The Mobile Infantry (MI) program will explore the development of a system-based, mixed team of mounted/ dismounted warfighters and semi-autonomous variants of current or planned small off-road platforms (equivalent to high-mobility platforms currently used by special forces operators single rider, two-rider, or four-rider variants). The MI mixed teams will be able to execute an expanded mission set from those currently employed. The MI system concept will allow for a combined set of mounted and dismounted operations and for a larger area of operations over more aggressive timelines than standard infantry units. To improve operational effectiveness of the warfighter teams when dismounted, the semi-autonomous platforms, when unmanned, act as multipliers to the squad, such as extended and mobile fire support platforms and allow the MI mixed teams to perform higher risk exposure and access missions. The MI system scale, enabled by smaller off-road platforms, is intended to maintain dismounted warfighter scales for operational deployment. Platforms are planned for internal transportation within CH-47, CH-53, and V-22 aircraft and are intended to be adaptations of existing/expected platforms to eliminate the schedule and cost of new platform development. ***FY 2016 Plans:*** - Complete trades of mission/vignette-driven collaborative command and control of a MI unit composed of a warfighter team and semi-autonomous systems. - Complete trade studies and initial estimates of perception and autonomous algorithms required to match vignettes. - Complete trade studies of candidate platforms and options for conversion, system integration, interfaces (electrical, mechanical, software, etc.), and define preliminary warfighter architectures to leverage. - Modify and demonstrate optionally manned configuration on an available all terrain vehicle.	-	-	6.000
Title: Robotics Challenge ***Description:*** The Robotics Challenge program will directly meet Department of Defense strategic needs by developing robotic technology for disaster response operations. This technology will improve the performance of robots that operate in the rough terrain and austere conditions characteristic of disasters, and use vehicles and tools commonly available in populated areas. This technology will work in ways easily understood by subject matter experts untrained in the operation of robots and be governed by	17.851	9.575	-

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-04 / *ADVANCED LAND SYSTEMS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
intuitive controls that require little training. The program will also meet the global need for resilience against natural disasters and industrial accidents, and increase the resilience of infrastructure against acts of terrorism. Anticipated Service users include the Army, Marines, and Special Forces. ***FY 2014 Accomplishments:*** - Built robot systems. - Developed algorithms for perception, manipulation, and operator interface. - Conducted the DARPA Robotics Challenge Trials. - Defined the DARPA Robotics Challenge Finals event performance and test criteria. ***FY 2015 Plans:*** - Conduct the DARPA Robotics Challenge Finals. - Perform analysis and report findings to document advancements achieved as a result of the challenge.			
Title: Robotics Fast Track ***Description:*** To be dominant in robotics of the future, the DoD will need to embrace programs designed to create disruptive advances in robotics capabilities that are measured in months rather than years, and whose individual costs may largely be measured in thousands of dollars rather than millions. The Robotics Fast Track program seeks to revolutionize robotics technologies by promoting non-traditional technical opportunities. The program will create low-cost, high-utility robotic component solutions by engaging a novel performer community in research efforts that result in prototype systems and proofs of concept in months, at a fraction of the cost of traditional design processes. The Robotics Fast Track program will engage numerous robotics related efforts across the spectrum of robotics professionals and enthusiasts, extending the existing performer base to include non-standard, cutting edge organizations and individuals throughout the robotics community. The program will demonstrate the ability for robotics projects to be performed at an asymmetric advantage in time, cost, and contribution of the efforts in comparison to more traditional applied research areas. This will apply to both performance of individual efforts and to the contracting required to engage performers in said efforts. ***FY 2014 Accomplishments:*** - Initiated outreach with nontraditional performer community. - Established baseline fundamental robotic system and subsystem needs. ***FY 2015 Plans:*** - Begin execution of multiple performance developments. - Release initial robotics fast track catalog.	1.500	8.000	-
Title: Fast, Adaptable, Next Generation Ground Combat Vehicle (FANG)	7.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-04 / *ADVANCED LAND SYSTEMS TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Description: The goals of the Fast, Adaptable, Next-Generation Ground Combat Vehicle (FANG) program were to employ a novel, model-based design and verification capability, a highly-adaptable foundry-style manufacturing capability, and collaborative design methods to demonstrate up to 5X compression in the timeline necessary to build an infantry fighting vehicle (IFV). The program sought to create an open-source development infrastructure for the aggregation of designer inputs applicable to complex electromechanical systems as well as software, and to exercise this infrastructure with a series of design events, leading to the building of designs in a foundry-style, rapidly configurable manufacturing facility. ***FY 2014 Accomplishments:*** - Conducted developmental testing and evaluation of the drivetrain and mobility subsystem built by the iFAB Foundry, including laboratory testing of a full up power pack (engine) and ground testing of a tracked vehicle. - Prepared notional design requirements for an IFV chassis and integrated survivability subsystem. - Conducted AVM tool suite validation testing, a rigorous test of META and iFAB capabilities executed by relevant industry teams and focused on the chassis and survivability subsystem of a heavy, amphibious IFV. - Transitioned component model standards, tool integration standards, and VehicleFORGE software tool suite and associated technology to the Digital Manufacturing and Design Innovation Institute (DMDII) through the use of co-funded research and formal technology transition activities for industry use. - Completed FANG Automotive Test Rig (ATR) build-out from the FANG Dynamometer Test Rig (DTR) Test Asset built by iFAB. - Executed Test Plan on FANG ATR Asset to compare real world performance with predicted performance in the AVM Tools. - Conducted focused iFAB manufacturing process capabilities assessment while transitioning AVM technologies to Army TARDEC and ARDEC (Benét Labs) through an End-to-End tool suite demonstration effort.			
Accomplishments/Planned Programs Subtotals	36.957	67.075	54.618

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency			Date: February 2015
Appropriation/Budget Activity 0400 / 2	R-1 Program Element (Number/Name) PE 0602702E / *TACTICAL TECHNOLOGY*	Project (Number/Name) TT-06 / *ADVANCED TACTICAL TECHNOLOGY*	

COST ($ in Millions)	Prior Years	FY 2014	FY 2015	FY 2016 Base	FY 2016 OCO	FY 2016 Total	FY 2017	FY 2018	FY 2019	FY 2020	Cost To Complete	Total Cost
TT-06: *ADVANCED TACTICAL TECHNOLOGY*	-	19.582	19.494	15.968	-	15.968	33.200	35.672	39.467	24.443	-	-

A. Mission Description and Budget Item Justification

This project focuses on broad technology areas including: a) compact, efficient, frequency-agile, diode-pumped, solid-state lasers for infrared countermeasures, laser radar, holographic laser sensors, communications, and high-power laser applications; and b) new tactical systems for enhanced air vehicle survivability, precision optics, electronic warfare, and advanced air breathing weapons.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Endurance	14.082	11.794	8.968
Description: The Endurance program will develop technology for pod-mounted lasers to protect a variety of airborne platforms from emerging and legacy electro-optical/infrared (EO/IR) guided surface-to-air missiles. The focus of the Endurance effort under TT-06 will be on miniaturizing component technologies, developing high-precision target tracking, identification, and lightweight agile beam control to support target engagement. The program will also focus on the phenomenology of laser-target interactions and associated threat vulnerabilities. The advanced technology component of this program is budgeted in PE 0603739E, Project MT-15. ***FY 2014 Accomplishments:*** - Developed preliminary designs for the objective brassboard system within the functional parameters of an objective flight-prototype. - Developed lethality data sets for representative legacy seekers. ***FY 2015 Plans:*** - Develop the critical design for the objective brassboard within the functional parameters of an objective flight prototype. - Develop a live-fire test plan in conjunction with all the stakeholders (Government test team, performer, target logistics, range support, range safety and environmental offices, laser clearing house etc.) ***FY 2016 Plans:*** - Obtain all necessary approvals (range-safety, environmental, and laser-clearing house, etc.) for conducting live-fire testing. - Develop detailed system and sub-system requirements for a flight-prototype of a pod-mounted laser weapon system.			
Title: LUSTER (Laser Ultraviolet Sources for Tactical Efficient Raman)	-	4.500	7.000
Description: The Laser UV Sources for Tactical Efficient Raman (LUSTER) program is developing a compact semiconductor laser that emits in the deep UV (i.e. wavelength <250 nanometers) and is capable of an output power of 1 Watt with high efficiency			

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency		Date: February 2015
Appropriation/Budget Activity 0400 / 2	**R-1 Program Element (Number/Name)** PE 0602702E / *TACTICAL TECHNOLOGY*	**Project (Number/Name)** TT-06 / *ADVANCED TACTICAL TECHNOLOGY*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
and spectral purity suitable for a wide array of spectroscopy applications. Such an achievement will represent a significant advance over the state of the art, as existing lasers in this wavelength range are bulky, highly inefficient, and expensive, as there are no available semiconductor lasers that can emit in the UV range <250nm. LUSTER will leverage lessons learned in growing high quality light emitting material from the Compact Mid-Ultraviolet Technology (CMUVT) program. The compact size of semiconductor lasers along with the LUSTER performance goals will enable many applications including but not limited to standoff Raman spectroscopy which is of interest for DoD applications such as chemical agent sensing. ***FY 2015 Plans:*** - Evaluate the design and growth of laser epitaxial material, focusing on low-defect growth, optimal electrical and optical confinement and methods for high efficiency and power operation. - Evaluate development of laser pumping technologies, such as the use of compact electron-beam sources. - Evaluate methods for using non-linear crystals to efficiently convert longer wavelength lasers in the 500 nanometer range down to the 250 nanometer range. ***FY 2016 Plans:*** - Optimize laser epitaxial material, electron-beam source, and frequency multiplying nonlinear crystals for higher efficiency and high power operation. - Develop compact low power electronics for driving and controlling photonic and mechanical components. - Demonstrate working prototype of a deep UV laser system that meets the phase 1 metrics of >100mW output power, 0.4% total system efficiency and line width less than 0.1nm.			
Title: International Space Station SPHERES Integrated Research Experiments (InSPIRE)	5.500	3.200	-
Description: The International Space Station SPHERES Integrated Research Experiments (InSPIRE) program utilizes the DARPA-sponsored Synchronized Position, Hold, Engage, and Reorient Experimental Satellites (SPHERES) platform, which has flown onboard the International Space Station (ISS) since May 2006, to perform a series of multi-body formation flight experiments that necessitate a medium-duration zero-gravity environment. InSPIRE enhances the ability to rapidly mature and insert new technologies into national security space assets. The InSPIRE program expands on the capabilities matured through SPHERES by developing, building and launching new hardware and software elements that expand the baseline capabilities. These capabilities enable use of SPHERES as a testbed for more complex experimentation, providing affordable opportunities to test new space technologies. ***FY 2014 Accomplishments:*** - Built and ground tested docking ports for SPHERES to enhance rendezvous and docking test capabilities. - Built and ground tested new structures for SPHERES that expand upon its ability to integrate with additional hardware. - Conducted testing of tele-operations capabilities on the SPHERES devices on ISS, from the ground.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Conducted testing of vision-based navigation hardware and software on the SPHERES devices on ISS. - Conducted testing of electromagnetic formation flight hardware and software on the SPHERES devices on ISS. - Developed and executed additional rendezvous and proximity operations experiments using SPHERES inside ISS. ***FY 2015 Plans:*** - Launch the new docking ports for SPHERES to enhance rendezvous and docking test capabilities. - Launch new structures for SPHERES that expand upon its ability to integrate with additional hardware. - Conduct on-orbit testing of new SPHERES docking ports and structures. - Develop and execute additional rendezvous and proximity operations experiments using SPHERES inside ISS.			
Accomplishments/Planned Programs Subtotals	19.582	19.494	15.968

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2016 Defense Advanced Research Projects Agency									Date: February 2015			
Appropriation/Budget Activity 0400 / 2					R-1 Program Element (Number/Name) PE 0602702E / *TACTICAL TECHNOLOGY*				Project (Number/Name) TT-07 / *AERONAUTICS TECHNOLOGY*			
COST ($ in Millions)	**Prior Years**	**FY 2014**	**FY 2015**	**FY 2016 Base**	**FY 2016 OCO**	**FY 2016 Total**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**Cost To Complete**	**Total Cost**
TT-07: *AERONAUTICS TECHNOLOGY*	-	44.951	46.961	39.971	-	39.971	44.942	47.361	55.424	42.434	-	-

A. Mission Description and Budget Item Justification

Aeronautics Technology efforts will address high payoff opportunities that dramatically reduce costs associated with advanced aeronautical systems and/or provide revolutionary new system capabilities for satisfying current and projected military mission requirements. This includes advanced technology studies of revolutionary propulsion and vehicle concepts, sophisticated fabrication methods, and examination of novel materials for aeronautic system applications.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
Title: Aircrew Labor In-cockpit Automation System (ALIAS)	5.000	17.000	23.971

Description: The Aircrew Labor In-cockpit Automation System (ALIAS) program will design, develop, and demonstrate a kit enabling affordable, rapid automation of selected aircrew functions across a broad range of aircraft. ALIAS intends to enable reduction of aircrew workload and/or the number of onboard aircrew, to improve performance. The program will develop hardware and software to automate select aircrew functions and will employ novel, low impact approaches to interfacing with existing aircraft monitoring and control systems. The program will also develop tractable approaches to rapidly capture crew-station specific skills and aircraft unique behaviors. To accomplish this, ALIAS will leverage recent advances in perception, manipulation, machine learning, reusable software architectures, autonomous systems architecture, and verification and validation. ALIAS will culminate in a demonstration of the ability to rapidly adapt a single system to multiple aircraft and execute simple missions. This reliability enhancement capability will enable new operational concepts for reuse of existing air assets and allow a reduction in the number of aircrew required.

FY 2014 Accomplishments:
- Executed a ground-based proof of concept study refining an approach to crew station interfacing.
- Initiated development of core crew station technologies.
- Initiated development of adaptable learning approaches.

FY 2015 Plans:
- Design and commence prototyping of an initial ground-based ALIAS system.
- Initiate simulator-based demonstration of complete automation system including training and adaptation of system to multiple crew member roles.
- Conduct ground or airborne risk reduction testing and demonstrations.

FY 2016 Plans:
- Perform ground demonstration of ALIAS system functionality.
- Conduct flight demonstration of contingency management and new command interface.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Demonstrate portability to new aircraft type. - Continue risk reduction activities.			
Title: Advanced Aeronautics Technologies ***Description:*** The Advanced Aeronautics Technologies program will examine and evaluate aeronautical technologies and concepts through applied research. These may include feasibility studies of novel or emergent materials, devices and tactics for both fixed and rotary wing air vehicle applications, as well as manufacturing and implementation approaches. The areas of interest range from propulsion to control techniques to solutions for aeronautic mission requirements. The result of these studies may lead to the design, development and improvement of prototypes. ***FY 2014 Accomplishments:*** - Performed testing of enabling technology components. - Initiated conceptual system designs. - Developed technology maturation plan and risk reduction strategy. ***FY 2015 Plans:*** - Initiate new studies of novel technologies. - Conduct risk reduction tests of candidate technologies. ***FY 2016 Plans:*** - Perform modeling of concepts and architectures. - Conduct trade studies of emerging concepts.	2.000	2.000	2.000
Title: Swarm Challenge ***Description:*** The goal of the Swarm Challenge is to develop autonomous swarming algorithms for Unmanned Vehicle (UxVs) to augment ground troops performing missions in a complex environment, without creating a significant cognitive burden. The program will evaluate the effectiveness of swarming for UxVs supporting ground operations, air operations, maritime operations, undersea operations, or search and rescue operations. Challenges include the ability for the UxV to collaborate to rapidly survey an area leveraging other UxVs to solve problems related to, for example, perception, decision making, or obstacle clearing. The challenge emphasizes minimum operator training and supervision so that the operator can continue to perform his/her normal duties while using UxVs as force multipliers. ***FY 2015 Plans:*** - Perform trade studies for system approach, functional and cognitive decomposition. - Select architecture for software, communication, computation, perception, and simulation environment.	-	3.000	6.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Develop autonomous algorithms and associated software. ***FY 2016 Plans:*** - Initiate first round of evaluation in simulated environment and then in physical environment. - Procure hardware and modify to enable demonstration of autonomy algorithms. - Improve cloud-based simulation environment and conduct virtual trials.			
Title: Gremlin ***Description:*** The goal of the Gremlin program is to develop platform technologies that enable a new class of distributed warfare. The Gremlin concept envisions small air-launched unmanned systems that can be responsively dispatched in volley quantity from commodity platforms, fly into contested airspace, conduct a moderate duration mission, and ultimately be recovered. Key enabling technologies for the concept include smaller developmental payloads that benefit from multiple collaborating host platforms. The Gremlin program will conduct risk reduction and development of the host platform launch and recovery capability and develop and demonstrate a recoverable UAV platform concept. Enabling platform technologies will include precision relative navigation, advanced computational modeling, variable geometry stores, compact propulsion systems, and high speed digital flight control. The program will leverage these technologies, perform analytic trade studies, conduct incremental development, and ultimately demonstrate the potential for an integrated air-launched Gremlin unmanned platform. ***FY 2016 Plans:*** - Conduct exploratory trade studies to establish feasibility of technical approaches. - Initiate studies on integration with existing Service systems and systems architectures. - Study platform design trades and approaches to best meet performance goals at minimum cost.	-	-	8.000
Title: Vertical Take-Off and Landing (VTOL) Technology Demonstrator ***Description:*** The Vertical Take-Off and Landing (VTOL) Technology Demonstrator program will demonstrate revolutionary improvements in (heavier than air) VTOL air vehicle capabilities and efficiencies through the development of subsystem and component technologies, aircraft configurations and system integration. The program will build and flight test an unmanned 10,000 - 12,000 lb aircraft capable of sustained speeds in excess of 300 kt, demonstrate system level hover efficiency within 25% of the ideal, and a lift-to-drag ratio no less than ten. Additionally, the demonstrator will be designed to have a useful load of no less than 40% of the gross weight. A strong emphasis will be placed on the development of elegant, multi-functional subsystem technologies that demonstrate net improvements in aircraft efficiencies to enable new and vastly improved operational capabilities. In FY 2016, VTOL Technology Demonstrator will be funded in PE 0603286E, Project AIR-01. ***FY 2014 Accomplishments:*** - Performed trade studies to refine configuration and subsystem designs. - Defined software and hardware integration approaches and baseline controls necessary for successful air vehicle concept.	34.951	21.961	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
- Performed simulations to establish expected system level performance and validated the system concept and underlying enabling technologies. - Conducted 3D, unsteady Computational Fluid Dynamics (CFD) analyses for design refinements and convergence. - Utilized multi-point optimization techniques for design of subsystems and aerodynamics. - Performed multiple sub-system, wind tunnel and aerodynamic tests utilizing rapid prototyping for design verification and validation. - Evaluated performance capabilities, and conducted objective aircraft operational analyses. - Evaluated technical and programmatic risk elements, defined mitigation plans and analyses of alternatives. - Completed conceptual design of configurations and all subsystems. - Refined and consolidated flight test and validation approaches, flight test missions, and test range requirements. ***FY 2015 Plans:*** - Initiate preliminary design of configuration and all subsystems. - Hold system definition reviews to evaluate subsystem integration into air vehicle design and technology development paths to meet program objectives. - Perform subscale wind tunnel and laboratory testing for aerodynamic data base and flight controls development. - Refine power generation and distribution/integration concepts. - Perform propulsion and power system scaled model bench testing. - Design and develop subscale flight models for configuration viability and control law validation. - Conduct subscale model flight testing for controls development, verification, and validation. - Validate computational performance predictions against empirical data. - Refine full scale engine integration design. - Continue preliminary design refinements leading toward detailed design of the demonstrator aircraft and associated subsystems. - Create detailed system integration plans. - Prepare detailed airworthiness and flight test preparation requirements in support of flight test schedule.			
Title: Petrel ***Description:*** The Petrel program will investigate and develop advanced capabilities for the rapid transport of large quantities of cargo and equipment, such as in support of the deployment of a heavy brigade combat team, from CONUS to the battlefield, reducing the deployment timeline for mechanized land forces and critical supplies anywhere in the world to under 7 days at a price point comparable or slightly in excess of conventional sealift. Petrel will fill the niche between conventional airlift and sealift through development of a new transportation mode capable of high speed operation across the surface/air interface over water as well as terrain. Technical approaches for rapid transport across the ocean and movement from the ship to the tactical battlefield will consider traditional and non-traditional aerodynamic and hydrodynamic concepts as well as innovative uses of	3.000	3.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2014	FY 2015	FY 2016
existing technologies. Primary technical goals for Petrel are to reduce or eliminate intermodal delays and to achieve a transport efficiency better than $0.1/ton-mi. ***FY 2014 Accomplishments:*** - Conducted studies to refine the operational trade space, defined limits of current technology, and informed new technical approaches. - Initiated concept designs focusing on transport efficiency, speed, and producibility. ***FY 2015 Plans:*** - Investigate component technologies with potential to enable specific concepts, including advanced propulsion and materials. - Explore innovative approaches for significantly increasing lift to drag ratio. - Evaluate approaches to rapidly deliver cargo and equipment directly from offshore to the battlefield without infrastructure. - Complete initial Petrel studies and conceptual system design work.			
Accomplishments/Planned Programs Subtotals	44.951	46.961	39.971

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.