Exhibit R-2, RDT&E Budget Item Justification: PB 2023 Defense Advanced Research Projects Agency	**Date:** April 2022
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 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
Total Program Element	-	449.322	443.842	401.870	-	401.870	396.555	439.811	447.586	447.640	-	-
CCS-02: *MATH AND COMPUTER SCIENCES*	-	273.633	293.845	224.416	-	224.416	208.185	248.752	264.013	256.785	-	-
ES-01: *ELECTRONIC SCIENCES*	-	28.681	16.361	17.645	-	17.645	29.153	34.178	52.200	52.410	-	-
ES-02: *BEYOND SCALING SCIENCES*	-	57.365	65.145	70.188	-	70.188	58.923	58.940	43.250	53.540	-	-
MS-01: *MATERIALS SCIENCES*	-	53.663	40.303	58.356	-	58.356	82.602	89.818	80.000	76.782	-	-
TRS-01: *TRANSFORMATIVE SCIENCES*	-	35.980	28.188	31.265	-	31.265	17.692	8.123	8.123	8.123	-	-

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, and materials sciences. This Program Element also supports innovation and robust transition planning in the technology cycle by working with entrepreneurs to increase the likelihood that DARPA funded technologies take root in the U.S. and provide new capabilities for national defense.

The Math and Computer Sciences project supports scientific study and experimentation on new mathematical and computational algorithms, models, and mechanisms in support of long-term national security objectives. Modern analytic and information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Conversely, new classes of threats, in particular threats that operate in or through the cyber domain, put military systems, critical infrastructure, and the civilian economy at risk. This project aims to magnify these opportunities and mitigate these threats by leveraging emerging mathematical and computational capabilities including artificial intelligence (AI), computational social science, machine learning and reasoning, data science, quantum science, complex systems modeling and simulation, and theories of computation and programming. The basic research conducted under the Math and Computer Sciences project will produce breakthroughs that enable new capabilities for national and homeland security.

The Electronic Sciences project is for basic exploration of electronic and optoelectronic devices, circuits, and processing concepts to meet the military's need for near real-time information gathering, transmission, and processing. In seeking to continue the phenomenal advancement in microelectronics innovation that has characterized the last few decades, the project should provide DoD with new, improved, or potentially revolutionary device options for accomplishing these critical functions. The resulting technologies should help maintain knowledge of the enemy, communicate decisions based on that knowledge, and substantially improve the cost and performance of military systems. Research areas include: analog, mixed signal, and photonic circuitry for communications and other applications; alternative computer

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architectures; and magnetic components to reduce the size of Electromagnetic (EM) and sensing systems. Other research could support field-portable electronics with reduced power requirements, ultra-high density information storage "on-a-chip", and new approaches to nanometer-scale structures, molecules, and devices.

The Beyond Scaling Sciences project supports investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon transistor scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through new non-volatile memory devices that combine computation and memory, and new automated design tools using machine learning. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Beyond Scaling programs will address fundamental exploration into each of these areas.

The Materials Sciences project provides the fundamental research that underpins the design, development, assembly, and optimization of advanced materials, devices, and systems for DoD applications in areas such as robust diagnostics and therapeutics, novel energetic materials, and complex hybrid systems.

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, and manufacturing. The project integrates these diverse disciplines to eliminate reliance on foreign sources for critical materials, improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens) and maintain warfighter health and improve recovery. This project also includes efforts to create innovative materials of interest to the military, as well as biological platforms for fabrication.

B. Program Change Summary ($ in Millions)	FY 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total
Previous President's Budget	474.158	395.781	0.000	-	0.000
Current President's Budget	449.322	443.842	401.870	-	401.870
Total Adjustments	-24.836	48.061	401.870	-	401.870
• Congressional General Reductions	0.000	-1.939			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	50.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-9.569	0.000			
• SBIR/STTR Transfer	-15.267	0.000			
• Adjustments to Budget Year	-	-	401.870	-	401.870

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Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2021	FY 2022
Project: CCS-02: *MATH AND COMPUTER SCIENCES*		
Congressional Add: *Foundational Artificial Intelligence - Congressional Add*	5.000	-
Congressional Add: *Alternative Computing - Congressional Add*	3.000	-
Congressional Add: *AI Cyber Data Analytics (AI) - Congressional Add*	-	10.000
Congressional Add: *AI Cyber Data Analytics (Cyber) - Congressional Add*	-	10.000
Congressional Add: *AI Cyber Data Analytics (Data) - Congressional Add*	-	10.000
Congressional Add Subtotals for Project: CCS-02	8.000	30.000
Project: ES-02: *BEYOND SCALING SCIENCES*		
Congressional Add: *ERI 2.0 Congressional Add*	-	20.000
Congressional Add Subtotals for Project: ES-02	-	20.000
Congressional Add Totals for all Projects	8.000	50.000

Change Summary Explanation

FY 2021: Decrease reflects reprogrammings and SBIR/STTR transfer.
FY 2022: Increase reflects Congressional adds for ERI 2.0 and AI Cyber & Data Analytics offset by a decrease for Sec. 8027 FFRDC.
FY 2023: FY 2023 funding increase reflects the fact that the FY 2022 President's Budget request did not include out-year funding.

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COST ($ in Millions)	Prior Years	FY 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	-	273.633	293.845	224.416	-	224.416	208.185	248.752	264.013	256.785	-	-

A. Mission Description and Budget Item Justification

The Math and Computer Sciences project supports scientific study and experimentation on new mathematical and computational algorithms, models, and mechanisms in support of long-term national security objectives. Modern analytic and information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Conversely, new classes of threats, in particular threats that operate in or through the cyber and information domain, put military systems, critical infrastructure, and the civilian economy at risk. This project aims to magnify these opportunities and mitigate these threats by leveraging emerging mathematical and computational capabilities including artificial intelligence (AI), computational social science, machine learning and reasoning, data science, quantum science, complex systems modeling and simulation, and theories of computation and programming. The basic research conducted under the Math and Computer Sciences project will produce breakthroughs that enable new capabilities for national and homeland security.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
Title: Foundational Artificial Intelligence (AI) Science	60.420	58.050	43.692

Description: The Foundational Artificial Intelligence (AI) Science thrust is developing a fundamental scientific basis for understanding and quantifying performance expectations and limits of AI technologies. Current AI technologies are challenged in handling uncertainty and incompleteness of training protocols and data. This has prevented the successful integration of AI technology into many transformative DoD applications. To address these limitations, the Foundational AI Science thrust will focus on the development of new learning architectures that enhance AI systems' ability to handle uncertainty, reduce vulnerabilities, and improve robustness for DoD AI systems. One focus area of this thrust is the ability to detect and accommodate novelty - i.e., violations of implicit or explicit assumptions - in AI applications. Another focus area is the development of a model framework for quantifying performance expectations and limits of AI systems as trusted human partners and collaborators. A third focus area is the development of new tools and methodologies that enable AI approaches for accelerated scientific discovery. The technology advances achieved under the Foundational AI Science thrust will ultimately remove technical barriers to exploiting AI technologies for scientific discovery, human-AI collaboration, accommodating novelties, and other DoD relevant applications.

FY 2022 Plans:
- Continue development of novelty generators and novelty-robust AI techniques to create and identify rapidly and respond appropriately to new agents, actions, relations, and interactions.
- Demonstrate and evaluate novelty generators and novelty-robust AI techniques compared to non-robust methods performing on known tasks incorporating new agents, actions, relations, and interactions.
- Develop methods to accurately correlate data across multiple sources, such as lab notebooks, tables, figures, and experimental databases.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Develop prediction models across multiple molecular properties of interest. - Demonstrate closed-loop feedback between experimental platforms and AI models to facilitate process optimization and inverse molecular design. - Demonstrate competency-aware machine learning behaviors and capabilities on integrated application platforms. - Experimentally test small-scale prototype hardware capable of information processing near the theoretical limit of energy efficiency and quantify the utility of quantum information processing systems for tasks related to machine learning. - Initiate investigation of how organizational culture affects AI systems generated by those organizations. - Demonstrate the accuracy of AI models for pneumothorax classification on a portable device. - Develop analysis tools to characterize patterns of open-source software contributor ascendency, identify critical code contributions, and map relevant social activity timelines to important code decisions in order to uncover key trends. - Demonstrate a basic capability to characterize and quantify the effectiveness of the information control techniques used by repressive governments to stifle free speech on the Internet. - Develop techniques to predict the behavior of deep neural networks applied to images using high-dimensional geometric tools, with emphasis on manifolds, manifold learning, and nonlinear dimensionality reduction. - Develop AI mediation technologies to encourage positive behavioral norms within a virtual social environment. - Examine approaches to preserve and promote positive factors of engagement in online discourse while minimizing the risk of negative social and psychological impacts. - Evaluate and refine AI agents and toolkit to understand nuanced communications and combine this with situational understanding to inform improved strategic decision-making and collaboration. - Initiate formulation of AI negotiation agents for multi-party interaction environments that include untrustworthy partnerships and dynamic goals. - Describe the technical approach for 1) intelligent array operations, 2) application development in a tensor-based programmable language, and 3) hardware implementation. - Develop a model that demonstrates the combined array and machine learning (ML) algorithms and how the intelligent array algorithms are abstracted to hardware-independent operations. Report on use cases descriptions of the new array-ML architecture. - Continue efforts to explore frontiers in Artificial Intelligence with a focus on third wave AI. ***FY 2023 Plans:*** - Demonstrate fully autonomous, closed-loop feedback between experimental platforms and AI models to facilitate process optimization and inverse molecular design. - Identify molecular design domains of greatest applicability for developed AI models and data representations. - Design baseline computational approaches for quantifying the alignment of an algorithmic decision maker with a reference group of human decision makers.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Initiate efforts to utilize information about the impact of organizational culture on AI systems. - Examine the feasibility of AI-enabled accelerated search of advanced functional materials without training dataset. - Demonstrate and evaluate novelty generators and novelty-robust AI techniques compared to non-robust methods performing on known tasks incorporating new rules, goals, and events. - Develop techniques for quantifying the uniqueness and stability of functions learned over manifolds, and formulate approaches for using these techniques to address issues related to adversarial, explainable, and trustworthy AI. - Further develop and test refined hybrid artificial intelligence (AI) models of climate processes, and explore their advantages over conventional models for rapid scenario analysis as well as for global and regional predictions. - Develop new AI architectures and ecosystems of "small AI" building blocks, enabling unconventional experimentation of AI ideas by individuals and small organizations. - Continue efforts to explore frontiers in Artificial Intelligence with a focus on third wave AI. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY2023 decrease reflects a shift in focus from design and development to technology demonstrations.			
Title: Alternative Computing ***Description:*** The Alternative Computing thrust is exploring and developing new computational primitives for modeling and simulating complex systems. Despite decades of rapid advancement in electronic computing, there remain important national security relevant challenge problems that do not lend themselves to achieving tractable solutions under size, weight, and power (SWaP) constrained conditions. For example, simulation of complex nonlinear phenomena such as turbulence, fluid flow, and plasma dynamics can be challenging even using currently available high power computing resources. Building on technologies developed under the Advanced Tools for Modeling and Simulation thrust, also in this PE/Project, the goal of the Alternative Computing thrust is to develop novel architectural and algorithmic approaches to enable fast and accurate simulations for problems that are practically intractable using electronic computers. Approaches considered under this thrust include the following: (1) analog computing substrates for efficiently simulating systems governed by complex non-linear phenomena; (2) multi-functional spin-based devices for scalable, efficient neuromorphic computing; (3) computing approaches that exploit the capacity of nonlinear systems to simulate nonlinear dynamical systems; and (4) quantum enabled optimization of complex systems. ***FY 2022 Plans:*** - Demonstrate the use of a near term quantum computer for solving combinatorial optimization problems. - Perform benchmarking of the quantum processor performance against the best classical system. - Initiate efforts to create new hardware agnostic benchmarks for quantum information processing performance that quantitatively measure progress towards specific, transformational computational challenges.	24.000	33.000	28.000

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Initiate development of scalable testing techniques for measuring progress in quantum information processing towards addressing specific, transformational computational challenges. - Initiate efforts to verify and validate at least one approach to fault-tolerant quantum computing. - Demonstrate a closed-loop verification system for fine-grained measurement of networks in which every packet is stamped by the forwarding elements to indicate the path it took, the queueing delay it experienced, and the rules it matched. ***FY 2023 Plans:*** - Experimentally demonstrate quantum optimization algorithms for combinatorial optimization problems for larger problem sizes. - Perform benchmarking of quantum optimization algorithms against the best classical method to demonstrate and quantify quantum advantage. - Select specific problems to focus on when developing hardware agnostic benchmarks for quantum information processing performance, prioritizing problems with the potential for transformational impact. - Identify core enabling mathematical operations underlying each of the selected hardware agnostic quantum benchmarks. - Establish initial hardware resource estimates for quantum computers that would be needed to solve specific problems with the potential for transformational impact. - Field and evaluate a closed-loop, verified, geographically dispersed network with operational nodes at multiple sites. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects a shift in focus from technology exploration to design and fabrication.			
Title: Agile Artificial Intelligence (AgAI) ***Description:*** The Agile Artificial Intelligence (AgAI) program aims to create the capability to rapidly stand-up AI in domains important to national security. In many significant domains with potentially urgent mission needs, labeled data may be sparse and costly to acquire, sensors and other data sources may be rapidly evolving in their capabilities, and requirements for reliability and traceability may be significant. Building on emerging technical opportunities in machine learning and symbolic reasoning, AgAI will create scientific and technological foundations for the agile creation and evolution of AI-based capabilities. Emerging technical areas that are critical to AgAI include explicit domain models, harmonization of statistical and symbolic approaches, hybridization of multiple AI methods with techniques including game theory and optimization, and meta-cognition to support rapid improvement of the AI capabilities themselves. The AgAI program will also combine emerging techniques for mathematical modeling and for explanation to enhance reliability and traceability of AI capabilities. ***FY 2022 Plans:*** - Explore the potential for a flexible, broadly-scoped AI development environment to support and facilitate the agile creation, maintenance, and improvement of AI and machine learning based systems across diverse application domains.	-	21.000	22.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Formulate repeatable approaches for harmonization of statistical and symbolic approaches, hybridization of multiple AI methods with techniques such as game theory and optimization, and meta-cognition to support rapid improvement of the AI capabilities themselves. - Conceptualize approaches for combining emerging techniques for mathematical modeling and for explanation to enhance reliability and traceability of the developed AI capabilities. ***FY 2023 Plans:*** - Develop a flexible, broadly-scoped AI development environment to support and facilitate the agile creation, maintenance, and ongoing improvement of AI and machine learning based systems across diverse application domains. - Develop integrated statistical-symbolic approaches, hybrid AI/game theory/optimization techniques, and meta-cognition for diverse applications such as strategic planning, modeling and simulation, knowledge management, transactional infrastructure, and financial services in austere environments. - Develop techniques for mathematical modeling and explanation generation to enhance reliability and traceability of the developed AI capabilities. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects minor program repricing.			
Title: Perceptually-Enabled Task Guidance (PTG) ***Description:*** The Perceptually-Enabled Task Guidance (PTG) program is developing artificial intelligence (AI) technology that guides users in the performance of a wide range of cognitively challenging physical tasks. PTG leverages recent advances in machine perception, automated reasoning, and augmented reality. The program will connect perception to reasoning and reasoning to augmented reality (AR) so as to create personalized, real-time feedback and contextualized assistance. To connect perception and reasoning, PTG will develop AI technologies for (1) perceptual grounding, to create a shared vocabulary for perception and reasoning, and (2) perceptual attention, to select important information from large volumes of perceptual data. To connect reasoning with AR, PTG will develop AI technologies for (3) knowledge transfer, to derive task models from instructions intended for humans, and (4) user modeling, to determine if, when, and how to best convey task information to the user. Together, the PTG technologies will lay the foundation for perceptually-enabled guidance and a qualitatively new type of AI device that enables mechanics, medics, and other military specialists to perform physical tasks within and beyond their skillsets with greater accuracy and efficiency. ***FY 2022 Plans:*** - Explore rule-based and statistical AI approaches for perceptual grounding, to create a shared vocabulary for perception and reasoning, and perceptual attention, to select important information from the large volumes of perceptual data.	6.330	12.234	17.300

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2021**	**FY 2022**	**FY 2023**
- Formulate approaches for connecting reasoning with AR, focusing on AI technologies for knowledge transfer, to derive task models from instructions intended for humans, and user modeling, to determine if, when, and how to best convey task information to the user. - Identify and collaborate with military stakeholders on high-priority task use cases, potentially involving repair of systems or emergency medical care, for demonstration and evaluation of integrated perceptual agent prototype systems. ***FY 2023 Plans:*** - Develop approaches for perceptual grounding as required for perceptually-enabled intelligent agents capable of learning how to recognize task-related terms, including objects, actions, and settings. - Devise new techniques for combining visual and audio examples scraped from multimedia knowledge sources and transferring them into task models, and for inferring model visual and audio properties from the properties of related model classes. - Develop knowledge transfer approaches for taking the knowledge that currently is available only in human-oriented task instructions such as checklists, procedure manuals, and training materials and representing that knowledge in machine-processable form. - Initiate integration of perceptual grounding, perceptual attention, knowledge transfer, and user modeling technologies and demonstrate and evaluate prototypes on a surrogate task use case, while working with military stakeholders on realistic high-priority task use cases. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects continued effort to develop foundational techniques for perceptually-enabled intelligent agents and increased efforts to integrate and demonstrate the techniques on surrogate and military task use cases.			
Title: Machine Common Sense (MCS) ***Description:*** The Machine Common Sense (MCS) program is exploring approaches to enable common sense reasoning by machines. Recent advances in machine learning have resulted in new artificial intelligence (AI) capabilities in areas such as image recognition, task-focused natural language processing, and strategy games such as Chess, Go, and Poker. In all of these application domains, the machine reasoning is narrow and highly specialized, and the machine must be carefully trained or programmed for every situation. This program addresses the challenge of general machine reasoning on par with common sense human cognition. MCS is developing computational models that mimic core systems of human cognitive development that are grounded in perceptual, motor, and memory modalities; a simulated interaction and learning environment to support machine manipulation of grounded concept models; and common sense knowledge repositories to support AI system development. AI systems that are capable of human-like reasoning will be able to behave more appropriately in unforeseen situations and to learn with reduced requirements for training data. ***FY 2022 Plans:***	16.500	18.000	17.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Develop core cognitive models with enhanced experience task learning capabilities, and evaluate model performance against experience learning tasks requiring elements of intuitive physics, navigation, and basic models of intentional agents. - Explore enhancements to core cognitive models, such as models of self-supervised intentional agents used by human infants, and evaluate model performance on prediction tasks. - Augment the simulation environment to support dynamic evaluation of a diverse set of machine learning methods, cognitive capabilities, prediction tasks, and experience learning tasks, including problems that require sensemaking, human-machine collaboration, or knowledge transfer. - Extend common knowledge capabilities to improve performance on common sense tasks with increased complexity, and develop novel common sense challenge problem benchmark suites for use in environments with complexity, noise, and novelty. ***FY 2023 Plans:*** - Develop agent models focused on understanding other agent intentions and demonstrate intentional agent reasoning. - Augment cognitive models with expanded experience learning capabilities, and enable self-evaluation modes for scenarios that require agent sensemaking, human-machine collaboration, and knowledge transfer. - Create evaluation techniques for generative question-answering for commonsense reasoning tasks, and extend capabilities to utilize cross-modal (text, image, video) data to improve performance. - Use the dynamic simulation environment to assess performance on benchmark common sense challenge problem suites in environments exhibiting high complexity, noise, and novelty. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects ramping down of work to develop machine common sense technologies and the simulation environment, and continued work to refine techniques and assess performance against benchmark common sense challenge problem suites.			
Title: Guaranteeing AI Robustness against Deception (GARD) ***Description:*** The Guaranteeing AI Robustness against Deception (GARD) program is developing techniques to defend against deception and other adversarial attacks on machine learning (ML) and artificial intelligence (AI) systems. GARD addresses the need to defend against deception attacks, whereby an adversary inputs engineered data into an ML system intending to cause the system to produce erroneous results. Deception attacks can enable adversaries to take control of autonomous systems, alter conclusions of ML-based decision support applications, and compromise tools and systems that rely on ML and AI technologies. Current techniques for defending ML and AI have proven brittle due to a focus on individual attack methods and weak methods for testing and evaluation. The GARD program is developing techniques that address the current limitations of defenses and produce ML and AI systems suitable for use in adversarial environments. The GARD program is also developing theory regarding potential fundamental limits on achievable ML robustness.	15.400	17.500	17.000

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
FY 2022 Plans: - Develop defenses against novel types of adversarial inputs, with particular interest in inputs that can be implemented in the physical world. - Develop and validate novel measures of attack strength, and integrate these measures into the evaluation framework. - Extend evaluation framework for testing ML defenses for adaptive-adversary scenarios, and implement and test ML defenses for use against an AI-enabled adversary. ***FY 2023 Plans:*** - Develop and validate measures of adversary costs and enhance defense methods to impose asymmetric costs on the adversary. - Demonstrate model training methods that reduce vulnerability to data poisoning. - Extend evaluation framework to support simulation environments and test physically plausible threat models. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects minor program repricing.			
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 cutting-edge 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 fifteen topic areas spanning from Machine Learning and Many Body Physics, to Wideband Transmitter-Antenna Interfaces and Multi-Scale Models of Infectious Disease Dynamics. 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 2022 Plans:*** - Award new FY 2022 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continue FY 2021 research on new concepts for microsystem, biological, strategic, and tactical technologies; information innovation; and defense sciences by exercising second year funding and by providing continued mentorship by program managers.	17.000	17.000	17.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Award Director's Fellowships for top FY 2020 participants to refine technology further and align to DoD needs. ***FY 2023 Plans:*** - Award new FY 2023 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continue FY 2022 research on new concepts for microsystem, biological, strategic, and tactical technologies; information innovation; and defense sciences by exercising second year funding and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2021 participants to refine technology further and align to DoD needs.			
Title: Knowledge Management at Scale ***Description:*** The Knowledge Management at Scale thrust is focused on the development of knowledge management tools that can efficiently capture, analyze and reason with expertise, experience and data. The technology development under this thrust will help address a critical need for assimilating and preserving critical national security knowledge and expertise that is currently being lost due to attrition and other factors. Specific objectives include the following: 1) effective, trustworthy, and easily accepted approaches for domain agnostic knowledge acquisition at scale; 2) capabilities to identify correlations or hidden factors relating to knowledge acquired from different sources; and 3) techniques for incorporating domain models and other data sources for more extensive reasoning-based applications. Example approaches towards achieving these objectives include identifying and demonstrating robust knowledge acquisition tools, exploiting Artificial Intelligence (AI) techniques to establish a framework for knowledge analysis and causal reasoning, and developing automation tools that effectively elicit and impart acquired knowledge via user friendly interfaces. ***FY 2022 Plans:*** - Develop novel AI tools capable of recognizing and representing implicit and explicit context of human tasks. - Develop automated methods to identify and capture, fuse, and disseminate knowledge across organizations as part of existing workflows. - Design and evaluate comfortable, trusted, and enticing software tools to be used by groups of non-technical people to capture, resolve, and apply effectively and timely different and overlapping aspects of their shared experiences at multiple time scales. - Use context to provide effective and appropriate knowledge from prior experience to current tasks. - Evaluate methods and tools in diverse task domains. ***FY 2023 Plans:*** - Extend novel AI tools capable of recognizing and representing implicit and explicit context of human tasks to scale to large organizations and diverse tasks. - Incorporate audio/video as input modalities into novel AI tools.	6.000	9.061	16.300

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B. Accomplishments/Planned Programs ($ in Millions)	**FY 2021**	**FY 2022**	**FY 2023**
- Evaluate novel AI tools in common domain of potential military interest. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects a shift from initial technology development to explorations of application spaces.			
Title: Artificial Social Intelligence for Successful Teams (ASIST) ***Description:*** The Artificial Social Intelligence for Successful Teams (ASIST) program is developing intelligent software agents that can create shared mental models to enable effective teaming with humans. Theory of mind and the ability to create shared mental models are key elements of human social intelligence. Together these capabilities enable human collaboration and teamwork at all scales, whether the setting is a playing field or a military mission. The ASIST program aims to develop technologies to enable machines to exhibit similar capabilities for collaboration and teamwork with humans, capabilities which can be termed artificial social intelligence. These include the capability to infer the goals and situational knowledge of human partners, to predict what human partners will need, and to formulate context-aware actions having high value to team outcomes. The ASIST program is developing proof-of-concept software agents that demonstrate a machine theory of mind and the capability to participate with humans in an effective team by representing and helping to maintain shared mental models. ASIST aims to provide the basis for machines that can participate effectively with humans on tasks where teamwork is required. ***FY 2022 Plans:*** - Demonstrate and test prototype computational agents that exhibit machine theory of mind and the ability to contribute to effective human teams in specialized environments. - Derive performance, trust, and acceptance predictions for computational agents capable of advising and guiding humans in the performance of complex tasks, thereby reducing the collective cognitive load. - Scale virtual testbed for evaluation of computational agents with artificial social skills in complex environments with teams of humans. ***FY 2023 Plans:*** - Develop and demonstrate computational agents that understand human social intelligence in a team context, can predict what is needed by partners, and intervene as an effective partner. - Develop agents able to handle perturbations in task, team, mission, and environment as needed for fast adaptation and team resilience. - Conduct experiments in multiple virtual testbed environments to demonstrate generalization across domains and relevance to DoD missions such as urban search and rescue, information operations, and cyber operations. ***FY 2022 to FY 2023 Increase/Decrease Statement:***	17.000	15.000	14.300

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCI ENCES*	**Project (Number/Name)** CCS-02 / *MATH AND COMPUTER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
The FY 2023 decrease reflects minor program repricing.			
Title: Human Social Systems	20.250	15.000	10.000

Description: The social sciences provide essential theories and models that can enable deeper understanding of human social systems and behaviors relevant to national security such as humanitarian aid, disaster relief, and stability support missions, as well as tactical, operational, strategic, and policy-level decision-making across the DoD. However, current limitations to the speed, scalability, and reproducibility of empirical social science research continue to hamper its practical use by the DoD. Additionally, current social behavioral models often fail to accurately interpret social behaviors because they do not sufficiently capture diversity of context. The Human Social Systems thrust will address these limitations by focusing on the following technical challenges: (1) developing and validating new methods, models and tools to perform rigorous, reproducible experimental research at scales necessary to understand emergent properties of human social systems; (2) identifying methods to better characterize and quantify properties, dynamics, and behaviors of different social systems to enable better and more confident forecasting of changes in social systems, particularly when under stress; (3) developing an understanding of the complex effect of context and incorporating these effects into social science models; and (4) developing strategic forecasting and operational decision aiding capabilities that account for local contextual and cultural factors to assess the likely effectiveness of and/or responses to actions within an Area of Operations. This research thrust will provide DoD with new, reliable strategies to better understand and respond to social system issues at multiple scales (from small group to cities and/or regions) and will significantly improve DoD stabilization, deterrence, and/or gray zone mission outcomes.

FY 2022 Plans:
- Test algorithms for automatically assigning quantitative confidence scores to social and behavioral science research.
- Analyze expert and non-expert usability and explainability of algorithms for automatically assigning quantitative confidence scores.
- Validate increased efficiency of algorithms for automatically assigning quantitative confidence scores to social and behavioral science research.
- Evaluate the accuracy of developed causal models of regional socioeconomic systems in representing the collective implicit casual models held by locals to the region.
- Investigate the amount of information that can be gathered remotely versus what must be gathered locally to create accurate, causal models of local socioeconomic systems.
- Demonstrate that mechanisms developed for engaging local populations are compatible with local infrastructure.
- Scope testbed for developing and understanding what metrics are appropriate for measuring the impact of actions such as in Influence Operations.
- Explore external and internal validity of social influence metrics within testbed.

FY 2023 Plans:

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Test the accuracy of causal models of regional socioeconomic systems derived from collective local understandings for predicting event outcomes compared to the current state of practice. - Evaluate the efficiency of methodologies for developing causal models of regional socioeconomic systems derived from collective local understanding compared to the current state of practice. - Continue to demonstrate that mechanisms developed for engaging local populations are compatible with local infrastructure and generate sufficient quality data to generate predictive causal models. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects a shift from development to demonstration.			
Title: Safe Documents (SafeDocs) ***Description:*** The Safe Documents (SafeDocs) program is developing software technologies that constrain syntactic complexity in data exchange formats, and improve the capability to reject invalid and maliciously crafted data in electronic documents and streaming data. The high complexity and unmanaged evolution of electronic document formats and streaming data protocols greatly increase the computational attack surface. The SafeDocs program is rationalizing existing data exchange formats significant to the defense mission, with attention to compatibility, and advancing the state of the art in the security of document and data format parsers. SafeDocs advances will enable automated code verification, assure that the conditions of data validity are enforced, and secure documents and streaming data. ***FY 2022 Plans:*** - Create methods for comparing multiple distinct classes of analytical information of parsing behaviors and rules, and develop techniques to merge and tag control flow graph blocks with derived semantics for streaming format parsers. - Develop machine-readable feedback mechanisms from format verification tools to improve system automation. - Automate testing methodologies and demonstrate safe parser construction using the developed tools. ***FY 2023 Plans:*** - Refine, improve, and validate the software parser prototypes for enterprise features relevant to both commercial and military systems. - Scale the test corpus to the size representative of a large enterprise and test the parsers for usability, predictability, and stability. - Refine and harden the technology to meet transition partner requirements and coordinate with industry and other stakeholders to standardize the simplified safe formats. ***FY 2022 to FY 2023 Increase/Decrease Statement:***	15.000	12.000	8.000

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
The FY 2023 decrease reflects ramping down of efforts to develop safe formats for electronic documents and streaming data and verified functionally correct, efficient parsers, and focus shifting to demonstration and transition of techniques.			
Title: Learning with Less Labeling (LwLL) ***Description:*** The Learning with Less Labeling (LwLL) program is developing technology to greatly reduce the amount of labeled data required to train machine learning (ML) systems. In supervised ML, a system learns through the use of labeled training examples to recognize and categorize attributes of images, text, or speech. Humans provide these training-data examples to ML systems and, with enough labeled data, it is generally possible to build useful models. Obtaining large amounts of labeled data can be costly, particularly for national security applications. LwLL is addressing this problem by creating ML algorithms that learn and adapt more efficiently than current ML approaches, and by formally deriving the limits of machine learning and adaptation. These algorithms achieve the goals through training with a combination of labeled and unlabeled data. LwLL aims to create ML systems that are easier to train for use in variable, unpredictable, real-world environments where training data is costly or sparse. ***FY 2022 Plans:*** - Develop approaches to optimize label reduction in ML algorithms and to simultaneously achieve performance near theoretical limits. - Demonstrate new ML algorithms that retain state-of-the-art performance even with several orders of magnitude reduction in labeled training data. - Demonstrate the generalization capability of new ML algorithms across multiple tasks. ***FY 2023 Plans:*** - Demonstrate ML systems that require less labeled training data in multiple domains relevant to the DoD, and transition technology to the DoD and industry. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects conclusion of development of ML techniques that require less labeled data for effective training, and focus shifting to demonstration and transition of techniques to the DoD and industry.	15.000	12.500	4.324
Title: Pipelined Reasoning of Verifiers Enabling Robust Systems (PROVERS) ***Description:*** The Pipelined Reasoning of Verifiers Enabling Robust Systems (PROVERS) program aims to advance the capability, scope, and usability of scalable mathematically based technologies, tools, and practices to achieve continuous reasoning about complex systems that can support software development pipelines. These mathematically based techniques, or formal methods, enable rigorous modeling, reasoning, and proving diverse properties of software code or design models, for example the absence of a specific type of defect or security vulnerability. PROVERS will integrate formal methods into a modern incremental and iterative development process by running tools at each code commit and delivering results to developers when	-	-	9.500

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
they can most effectively remediate discovered issues. To achieve this, PROVERS will focus on creating and sustaining a body of evidence that can co-evolve with the system under change to support continuous assessment and ensure that the system remains free of identified categories of defects and security vulnerabilities through its lifetime. Key PROVERS objectives include enabling proof maintenance and repair capabilities at a cost that is proportionate to code change; integration of formal methods with code, properties, and proofs in a single workflow that reduces human involvement; providing improved explanations to facilitate proof repair; and automating formal methods-based software analysis to support software developers that are not formal methods experts. PROVERS technologies will facilitate the agile development and continuous improvement of mission-critical software systems that meet the high security and quality standards required by the DoD. ***FY 2023 Plans:*** - Explore formal methods approaches and develop tools and data management techniques appropriate for pipelined software development processes and incremental proof maintenance and repair. - Formulate mathematical approaches for proof engineering at scale including techniques such as distributed proofs. - Identify candidate mission-critical software applications and systems for controlled formal-methods-based experiments with the goal of quantifying the improvements in development productivity and system security. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects program initiation.			
Title: World Modelers ***Description:*** The World Modelers program is creating explanatory models for complex natural and human-mediated systems at regional and global scales. Because of macro-economic interdependence, widespread consequences can result from the disruption of natural resources, supply chains, and production systems. World Modelers capabilities are focused on regional and global systems with the goal of generating timely indications and warnings. Water and food security are application domains of particular interest, as persistent drought may cause crops to fail, leading to migration and regional conflicts. The World Modelers program aims to develop techniques for automating the creation, maintenance, and validation of large-scale integrated models using publicly available news and analyst reports as a structuring mechanism, and government and commercial data as quantitative inputs. ***FY 2022 Plans:*** - Integrate software capabilities applicable to the diverse data and modeling tasks encountered in high-priority use cases. - Demonstrate modeling modalities in support of analytic workflows in diverse domains and optimize techniques in response to user feedback.	13.700	12.000	-

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Harden technologies and perform evaluations in collaboration with transition partners. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects program completion.			
Title: Analyzing Software to Protect against Evolving Cyber Threats (ASPECT) ***Description:*** The Analyzing Software to Protect against Evolving Cyber Threats (ASPECT) program is developing technologies to enable software developers to pose in-depth queries of code under development and sustainment in order to discover negative patterns, capture the semantic features of vulnerability classes, and characterize undesirable behaviors. ASPECT technologies will enable developers to generate the types of evidence required for confident certification, thereby improving software quality and assurance. At present, software faults and vulnerabilities are often unwittingly propagated throughout the software ecosystem because they are not easily discovered in codebases and because developers have strong incentives to re-use code and programming patterns. Moreover, searching for faults and vulnerabilities in software is impractical because these flaws are not manifest through the syntax of the source code but rather through the behaviors encoded in the software, i.e., in the software semantics. ASPECT will enable developers to query software at this deeper semantic level by developing modeling languages for the semantics of code and programs; representing code and programs in terms of their semantics; and identifying negative patterns, potential vulnerabilities, and undesirable behaviors. ***FY 2022 Plans:*** - Develop semantically-based metrics of software quality and evidence management techniques that provide actionable or otherwise useful information for software developers. - Identify categories of latent vulnerabilities including syntactically-distinct but semantically-equivalent instances. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects program completion.	4.000	8.500	-
Title: Advanced Tools for Modeling and Simulation ***Description:*** The Advanced Tools for Modeling and Simulation thrust is developing foundational mathematical, computational, and multi-physics theories, approaches, and tools to better represent, quantify, and model complex DoD systems from multimodal data analysis through part/system design and fabrication. One focus area of this thrust is developing a unified mathematical framework to enable better visualization and analysis of massive, complex data sets. Rigorous mathematical theories are also being developed to address uncertainty in the modeling and design of complex multi-scale physical and engineering systems, incorporating capabilities to handle noisy data and model uncertainty that are well beyond the scope of current capabilities. Other work in this thrust focuses on developing the mathematical and computational tools required to generate and better manage the enormous complexity of design, ultimately allowing designers to more easily discover non-intuitive (yet realizable) designs that	6.765	3.000	-

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
fully leverage new materials and advanced manufacturing approaches now available. Outcomes from this thrust will improve the speed and accuracy of modeling and simulation, as well as enable management of complexity across DoD devices, parts, and systems. Another focus area of this thrust is multi-physics models for predicting behavior and non-intuitive failure pathways for complex, dynamic physical systems. ***FY 2022 Plans:*** - Explore applications of multi-basis imaging techniques via modeling and simulation. - Explore the effectiveness of modelling and simulating complex correlated systems using quantum-inspired mathematical techniques. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease is due to program completion.			
Title: Synergistic Discovery and Design (SD2) ***Description:*** The Synergistic Discovery and Design (SD2) program developed data-driven methods to accelerate scientific discovery and robust design in domains that lack complete models. Engineers regularly use high-fidelity simulations to create robust designs in complex domains such as aeronautics and integrated circuits. In contrast, robust design remains elusive in domains such as synthetic biology, neuro-computation, and synthetic chemistry due to the lack of high-fidelity models. The SD2 program developed technologies to collect raw experimental data into a data and analysis hub, computational techniques that extract scientific knowledge directly from experimental data, and data sharing tools and metrics that facilitate collaborative design. SD2 application domains include synthetic biology, solar cell chemistry, and protein design, which will impact future DoD capabilities in areas such as chemical and biological defense, and warfighter readiness.	16.000	-	-
Title: Complex Hybrid Systems ***Description:*** The Complex Hybrid Systems program was focused on exploring fundamental science, mathematics, and computational approaches to collectives, complex hybrid (e.g., human-machine) systems and systems-of-systems across a variety of DoD-relevant domains. Efforts include development of foundational, quantitative theories and algorithms for the analysis and design of complex systems, as well as novel testing capabilities for assessing the value of these theories using experimental verification across multiple problem domains. Results from this program better enabled the systematic design of complex hybrid systems helping to achieve unprecedented resilience and adaptability in unexpected environments.	7.300	-	-
Title: Communicating With Computers (CWC) ***Description:*** The Communicating With Computers (CWC) program advanced the state-of-the-art in human-computer interaction by enabling computers to comprehend language, gesture, facial expression, and other communicative modalities in context.	4.968	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
Human language is inherently ambiguous, so humans depend on additional communication pathways, including perception of the physical world and shared context, to communicate efficiently. CWC developed techniques to provide computers with analogous capabilities to sense and encode aspects of the physical world in a perceptual structure, and to use this structure to disambiguate language. To accomplish this, CWC applied and extended research in language, vision, gesture recognition and interpretation, dialog management, cognitive linguistics, and the psychology of visual encoding. CWC also extended the communication techniques developed for physical contexts to nonphysical contexts and virtual constructs.			
Accomplishments/Planned Programs Subtotals	265.633	263.845	224.416

	FY 2021	FY 2022
Congressional Add: Foundational Artificial Intelligence - Congressional Add ***FY 2021 Accomplishments:*** - Developed and applied symbolic and statistical Artificial Intelligence (AI) techniques to understand collaborative open-source software development activities at scale and to detect patterns of manipulation that have the potential to expose critical information, defeat mitigations even as they are being implemented, or otherwise degrade security.	5.000	-
Congressional Add: Alternative Computing - Congressional Add ***FY 2021 Accomplishments:*** - Assessed point designs in the lossy, noisy regime for a commercial quantum computing architecture to strengthen understanding of the viability of the approach.	3.000	-
Congressional Add: AI Cyber Data Analytics (AI) - Congressional Add ***FY 2022 Plans:*** Explore the feasibility of so-called adaptive de-learning by machine learning systems, whereby learning that was performed using invalid data can be backed out of the system without retraining the entire system from scratch.	-	10.000
Congressional Add: AI Cyber Data Analytics (Cyber) - Congressional Add ***FY 2022 Plans:*** Develop high assurance computing architectures suitable for mission-critical systems that must operate with resilience in contested environments.	-	10.000
Congressional Add: AI Cyber Data Analytics (Data) - Congressional Add ***FY 2022 Plans:*** Develop high assurance computing architectures suitable for mission-critical systems that must operate with resilience in contested environments.	-	10.000
Congressional Adds Subtotals	8.000	30.000

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		**Date:** April 2022
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 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	-	28.681	16.361	17.645	-	17.645	29.153	34.178	52.200	52.410	-	-

A. Mission Description and Budget Item Justification

The Electronic Sciences project is for basic exploration of electronic and optoelectronic devices, circuits, and processing concepts to meet the military's need for near real-time information gathering, transmission, and processing. In seeking to continue the phenomenal advancement in microelectronics innovation that has characterized the last few decades, the project should provide DoD with new, improved, or potentially revolutionary device options for accomplishing these critical functions. The resulting technologies should help maintain knowledge of the enemy, communicate decisions based on that knowledge, and substantially improve the cost and performance of military systems. Research areas include analog, mixed signal, and photonic circuitry for communications and other applications; alternative computer architectures; and magnetic components to reduce the size of Electromagnetic (EM) and sensing systems. Other research could support field-portable electronics with reduced power requirements, ultra-high density information storage "on-a-chip", and new approaches to nanometer-scale structures, molecules, and devices.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
Title: Atomic-Photonic Integration (A-PhI)	14.681	9.361	9.000

Description: The Atomic-Photonic Integration (A-PhI) program is reducing the size, weight, and power of atomic clocks and gyroscopes for position, navigation, and timing (PNT) applications through the development of integrated photonics. Specifically, A-PhI will demonstrate that a compact photonic integrated chip can replace the optical assembly for trapped atomic gyroscopes and clocks without degrading the performance of the device. PNT is a critical resource for all DoD missions such as communications, navigation, reconnaissance, and electronic warfare. While PNT needs usually are met by using the global positioning system (GPS), GPS signals are vulnerable to a variety of disruption modalities and a fallback from GPS is essential. In the absence of GPS, tactical grade clocks and tactical/navigation grade inertial measurement units (IMUs) currently can provide GPS-like accuracy only for the short term, and longer-term GPS independent strategies are highly desirable. A-PhI will enable long-term GPS independence and enable better-than-GPS PNT accuracy for short durations.

FY 2022 Plans:
- Demonstrate an atomic clock physics package meeting size, frequency stability, and phase noise metrics.
- Improve atom trap gyroscope sensitivity.

FY 2023 Plans:
- Demonstrate a trapped atom gyroscope with single measurement angle rate resolution and scale factor exceeding commercial gyroscopes.
- Test integrated photonics based atomic clock by referencing to civilian and military time standards at National Institute of Standards and Technology (NIST) and United States Naval Observatory (UNSO).

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Initiate research into other reference frequency sources, such as sub-millimeter wave oscillators, with the potential to achieve atomic clock-level accuracy, precision, and stability. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects minor program repricing.			
Title: Ultra-Wide Bandgap Semiconductors (UWBG) ***Description:*** The Ultra-Wide Bandgap Semiconductors (UWBG) program will seek to develop an entirely new class of semiconductor materials that will offer performance breakthroughs for a range of applications when compared to existing compound semiconductors. Electrical bandgap determines a material breakdown voltage, intrinsic charge carrier density, and color (wavelength) of light emission, and also impacts the maximum output power and operating frequency of a transistor made from the material. Consequently, wide bandgaps have considerable interest for the DoD due to the high operating temperatures, currents, voltages, and frequencies often required by emerging high power, agile Radio Frequency (RF) sources for radar, communications, directed energy, and electronic warfare. This program will overcome the fundamental materials and device challenges that currently prevent implementation of UWBG materials into power, RF, and optoelectronic devices and systems. These challenges include reliably manufacturing low-defect substrates, heteroepitaxial material growth, and high concentration p-type and n-type doping. ***FY 2022 Plans:*** - Design low-energy heterogeneous epitaxially-grown UWBG devices. - Develop theoretical models of high-energy performance and avalanche breakdown in UWBG materials. ***FY 2023 Plans:*** - Characterize low-energy heterogeneous epitaxially-grown UWBG devices. - Experimentally verify theoretical models of high-energy performance and avalanche breakdown in UWBG materials. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects transition from basic design efforts to characterization and experimental verification of devices and models.	1.000	7.000	8.645
Title: Magnetic Miniaturized and Monolithically Integrated Components (M3IC) ***Description:*** The Magnetic Miniaturized and Monolithically Integrated Components (M3IC) program integrated magnetic components onto semiconductor materials, improving the size and functionality of electromagnetic (EM) systems for communications, radar, and electronic warfare (EW). The M3IC program was divided into three technical areas: integration of magnetic materials and systems with semiconductor technology, accurate and efficient modeling of magnetic phenomena from	8.000	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
the molecular to the system level, and exploitation of magnetic phenomena in innovative component designs relevant to DoD EM systems.			
Title: A MEchanically Based Antenna (AMEBA) ***Description:*** The A MEchanically Based Antenna (AMEBA) program developed and demonstrated efficient radio frequency (RF) transmitters operating in the Ultra-Low Frequency (ULF) and Very Low Frequency (VLF) ranges for portable applications in underground and underwater communications. Whereas traditional antennas generate electromagnetic waves by driving current through a conductive material, AMEBA took the novel approach of mechanically moving an electrical charge or magnet to generate electromagnetic waves at ULF and VLF. AMEBA focused on developing both the materials and precision-controlled electromechanical systems required for an efficient transmitter system. This new capability enables a range of applications including wireless communications for use over very long distances and short-range underground and underwater RF links. Other potential applications include terrestrial navigation systems for GPS-denied environments and ground-penetrating radar for detecting unexploded ordnance, underground facilities, and tunnels.	5.000	-	-
Accomplishments/Planned Programs Subtotals	28.681	16.361	17.645

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		**Date:** April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

COST ($ in Millions)	Prior Years	FY 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
ES-02: *BEYOND SCALING SCIENCES*	-	57.365	65.145	70.188	-	70.188	58.923	58.940	43.250	53.540	-	-

A. Mission Description and Budget Item Justification

The Beyond Scaling Sciences project supports investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon transistor scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through new non-volatile memory devices that combine computation and memory, and new automated design tools using machine learning. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Additionally, new design and manufacturing advances for three-dimensional microelectronics integration will underpin continued performance improvements as silicon transistor scaling plateaus. Beyond Scaling programs will address fundamental exploration into each of these areas.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
Title: Beyond Scaling - Materials ***Description:*** The Beyond Scaling - Materials program investigates new materials to support next-generation logic and memory components. The program pursues potential enhancements in electronics that do not rely on Moore's Law, i.e. silicon transistor scaling, including research into new materials and into the implications of those materials at the device, algorithm, and packaging levels. These basic explorations include novel mechanisms for computation based on inherent material properties and innovative processes to vertically integrate these materials with others to realize superior computational mechanisms. Applied research for this program is funded within PE 0602716E, Project ELT-02. ***FY 2022 Plans:*** - Design energy efficient in-memory computing processing units with high energy efficiency per operation. - Design advanced compute units for advanced DoD-relevant machine learning applications. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects program completion.	11.000	5.000	-
Title: Low Temperature Logic Technology (LTLT)* ***Description:*** *Previously part of Beyond Scaling - Materials The Low Temperature Logic Technology (LTLT) program will exploit the unique device and material performance characteristics of state-of-the-art silicon transistors at cryogenic temperatures. Current silicon transistors are performance and power limited	-	3.000	13.000

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
when operating at room temperature or higher. This program removes these limitations through modifying the design of existing silicon transistors to optimize their performance at cryogenic temperatures. These devices will be compatible with current complementary metal-oxide-semiconductor (CMOS) fabrication process flows and will offer significant increases in performance and power efficiency over room temperature devices. This program has applied research efforts funded in PE 0602716E, Project ELT-02. ***FY 2022 Plans:*** - Initiate simulations of transistor, memory, and interconnects for low temperature circuits. - Simulate and analyze transistor, memory, and interconnect performance at low temperature for low temperature circuits. ***FY 2023 Plans:*** - Perform initial design of low temperature transistors, memory, and interconnects for low temperature circuits. - Refine simulations of transistor, memory, and interconnect performance at low temperature for low temperature circuits. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects the program moving from simulation and analysis to design of low temperature circuits.			
Title: Beyond Scaling - Architectures and Designs ***Description:*** The Beyond Scaling - Architectures and Designs program investigates circuit architectures and design tools at both the integrated circuit and board level to provide enhanced performance and security with or without the benefit of continued silicon transistors scaling (Moore's Law). Currently, improvements in electronics largely depend on a regular reduction in the size of silicon components. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics performance, DoD will need to maximize the benefits of available silicon technologies through circuit specialization. This program investigates the potential for lowering the barriers to designing specialized circuits and to incorporating privacy and security protections. Approaches include the use of machine learning and automated design tools to program specialized hardware blocks, integrate them into existing designs, and deploy them in complex systems. This program will also support a new DoD capability to create secure and specialized hardware that does not depend on continued improvements in silicon transistors. Applied research for this program is funded within PE 0602716E, Project ELT-02. ***FY 2022 Plans:*** - Fabricate and test automatically generated digital and analog integrated circuits created using program-developed open source software tools. - Develop specialized machine designed hardware, and benchmark against general purpose machine learning chips. ***FY 2022 to FY 2023 Increase/Decrease Statement:***	10.000	6.645	-

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
The FY 2023 decrease reflects program completion.			
Title: Guaranteed Architectures for Physical Security (GAPS)* ***Description:*** *Previously part of Beyond Scaling - Architectures and Design The Guaranteed Architectures for Physical Security (GAPS) program is developing hardware security and software architectures with provable security interfaces. These interfaces will physically isolate high-risk transactions during both system design and system build, and will ensure that such protections are enforced at run-time. GAPS will reduce the inherent complexity through the development of hardware and software that is open, extendible, and compatible with size, weight, and power constrained environments to enable security across DoD and commercial systems. The program will substantially lower the barrier to safely enabling high-risk transactions, thus allowing for fast computer-to-computer transactions, physical spatial isolation reducing the need for unreliable software partitioning solutions, and more complex missions without putting sensitive data at risk. This program has applied research efforts funded in PE 0602716E, Project ELT-02. ***FY 2022 Plans:*** - Demonstrate the implementation of novel provably-secure hardware with computation overheads that are practical for real-world use. - Perform design for the integration of provably-secure hardware into multi-level security architecture. ***FY 2023 Plans:*** - Demonstrate integration of provably-secure hardware into multi-level security architecture. - Perform initial testing of integrated provably-secure hardware. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects the program moving from design to integration and testing.	4.000	4.000	9.000
Title: Ferroelectric Computing (FC) ***Description:*** The Ferroelectric Computing (FC) program will develop advanced complementary metal oxide semiconductor (CMOS)-compatible ferroelectric transistor technology, compute-in-memory element, and memory compute array technologies for critical data-intensive DoD applications such as radar processing, signal intercept and identification, and image processing. Current compute-in-memory devices are not compatible with advanced CMOS, and are too large to be scaled to the performance and efficiency levels necessary to support these applications. This program will address this shortfall by developing CMOS-compatible ferroelectric transistor technology for next-generation power-efficient, dense, and scalable compute-in-memory accelerators. This program has applied research efforts funded in PE 0602716E, Project ELT-02. ***FY 2022 Plans:***	-	3.000	10.188

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Analyze material properties and device characteristics to evaluate suitability for use in a ferroelectric transistor. ***FY 2023 Plans:*** - Simulate performance of ferroelectric transistors and analyze potential impact for high efficiency processing. - Perform initial designs of ferroelectric transistor architectures from simulation data. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects additional fundamental research activities in ferroelectric materials and transistors.			
Title: Next Generation Microelectronics - Advanced Manufacturing Science ***Description:*** Next Generation Microelectronics - Advanced Manufacturing Science addresses the fundamental science of advanced design, fabrication, packaging, assembly, and testing for complex microsystems. This area also addresses leveraging the underlying device physics of novel material systems to enable electronics that operate in extreme environments, such as environments with high voltage, high current, high temperature, low temperature, and radiation exposure. This effort will build upon a fundamental understanding of the materials, interconnects, and device technologies to enable the design, assembly, testing, and digital emulation of three-dimensional heterogeneous integration (3DHI) in microsystems, and their use in both standard and extreme environments. The physics of interfaces between similar and dissimilar materials and the ability to characterize and reduce defect densities will be critical to the future of 3DHI approaches. In addition, the physics of electron transport, photon transport, and heat dissipation are key areas of study. Materials advances and metrology that improve the reliability of heterogeneously integrated microsystems will be addressed, including those that enable high current density for power delivery. Applied research related to this effort is funded within PE 0602716E, Project ELT-02. ***FY 2023 Plans:*** - Investigate electrical characterization techniques and metrology for three-dimensionally interconnected microsystems and thermally hardened microsystems. - Identify the surface and interface physics to allow precisely aligned, high-density interconnects for digital components. - Explore novel materials and material systems to extend temperature operation range and to improved management of thermal interfaces, leveraging artificial intelligence (AI) and additive manufacturing. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects program initiation.	-	-	20.000
Title: Joint University Microelectronics Program 2.0 (JUMP 2.0) ***Description:*** The Joint University Microelectronics Program 2.0 (JUMP 2.0) program will develop and demonstrate innovative next-generation microelectronics technologies through public-private partnership with universities, the defense industrial base, and the semiconductor industry. The JUMP 2.0 program addresses the grand technical challenges of our increasingly connected	-	-	18.000

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
world that must be overcome including: the need for innovation in analog hardware, increasing demand for more memory and data storage, the imbalance between data generation and communication capacity, the emerging security vulnerabilities in highly-interconnected Artificial Intelligent systems, and the unsustainable growth in energy demands for computing. Therefore, the JUMP 2.0 program sponsors academic research teams focused on related key technology areas that will not only impact future defense and national security capabilities but also strengthen U.S. leadership in information and communication technology. The JUMP 2.0 program will push fundamental technology research themes in cognition, communications, sensing to action, computing and processing, memory and storage, integration and packaging, and high-performance energy efficient devices to enable key disruptive advances in microelectronic technology. ***FY 2023 Plans:*** - Launch university research teams to study technical areas with long-term impacts to government and industry. - Explore high-performance energy-efficient materials, devices, and 3D integration technology for future microsystems. - Investigate cognition, communications, sensing to action, computing and processing, integration and packaging, and high-performance energy efficient devices. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects program initiation.			
Title: Joint University Microelectronics Program (JUMP) ***Description:*** The Joint University Microelectronics Program (JUMP) is a government-industry joint research program to explore computing, sensing, communication, and data storage innovations for applications beyond the 2030 horizon. The program recognizes that the densely interconnected microsystems of the future will be built through the use of groundbreaking materials, revolutionary devices, advanced architectures, and unconventional computing. Therefore, JUMP sponsors academic research teams focused on related key technology areas that will impact future DoD capabilities and national security. The JUMP program will not only push fundamental technology research but also establish long-range microelectronic research themes with greater emphasis on end-application and systems-level computation. By discovering the science underlying new technologies and overcoming engineering challenges, JUMP will enable DoD applications to exploit the entire electromagnetic spectrum from radio frequency (RF) to terahertz (THz) and to employ both distributed and centralized computing with embedded intelligence and memory. ***FY 2022 Plans:*** - Advance materials, power efficient RF, THz, digital, and storage devices for technology adoption or transition.	18.000	18.000	-

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
- Demonstrate next-generation distributed and centralized computing architectures and subsystems with enhanced efficiency of information extraction, processing, and autonomous control. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects program completion.			
Title: Lifelong Learning Machines (L2M) ***Description:*** The Lifelong Learning Machines (L2M) program is researching and developing fundamentally new machine learning mechanisms, enabling machines that learn continuously as they operate. Current learning machines are fully configured in advance of deployment, and so have difficulty accounting for in-the-field mission changes or unexpected deviations in the data being processed. To overcome this limitation, L2M will pursue learning approaches inspired by biological systems, which continuously learn and improve their skills without losing previous knowledge. L2M will explore network structures that improve performance by processing new data seen in the field, learn new tasks without forgetting previous tasks, and incorporate context into their understanding of the environment. These capabilities would impact a broad array of military applications that require processing and understanding data in real-time, often have limited data sets for training, and must be deployed in environments where unpredictable events may occur. ***FY 2022 Plans:*** - Demonstrate integrated L2M systems in multiple domains. - Transition L2M algorithms into selected applications. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects program completion.	14.365	5.500	-
Accomplishments/Planned Programs Subtotals	57.365	45.145	70.188

	FY 2021	FY 2022
Congressional Add: ERI 2.0 Congressional Add ***FY 2022 Plans:*** - Initiate developing new material systems to extend temperature operation range for thermally-hardened and high-reliability microsystems. - Initiate developing new materials for three-dimensional heterogeneous integration (3DHI) photonics. - Identify new materials and structures for passive components for 3DHI power modules. - Develop novel materials for reducing losses in vertical high frequency interconnects for 3DHI microsystems.	-	20.000
Congressional Adds Subtotals	-	20.000

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		**Date:** April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** MS-01 / *MATERIALS SCIENCES*

COST ($ in Millions)	Prior Years	FY 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	-	53.663	40.303	58.356	-	58.356	82.602	89.818	80.000	76.782	-	-

A. Mission Description and Budget Item Justification

The Materials Sciences project provides the fundamental research that underpins the design, development, assembly, and optimization of advanced materials, devices, and systems for DoD applications in areas such as robust diagnostics and therapeutics, novel energetic materials, and complex hybrid systems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
Title: Molecular Systems and Materials Assembly	5.500	10.000	24.900

Description: The Molecular Systems and Materials Assembly thrust is exploring new approaches for the synthesis, assembly, characterization and application of molecules and materials for a variety of DoD applications from the atomic to the product scale. Ultimately, materials and methods developed in this thrust will support a wide range of DoD applications that span electrochemical energy storage, corrosion resistant materials, data storage and nutrient generation. Specific approaches include understanding and controlling interfacial phenomena, developing technologies for microbial production of macronutrients (e.g., proteins and carbohydrates) and exploiting molecules for use in data storage and computing. Efforts in this thrust range from fundamental science to better understand the chemistry and physics related to each application, to developing means to utilize such capabilities in future test systems and prototype devices.

FY 2022 Plans:
- Assess novel approaches to use local energy gradients to sense onset of damage and enable restoration of morphology and function in electrochemical interfaces.
- Initiate efforts to enable production of food on demand at point of consumption that addresses supply line vulnerabilities.

FY 2023 Plans:
- Discover or design novel materials and materials-architectures that can self-regulate morphology in electrochemical interfaces.
- Assess system level persistence improvements in solid-state batteries such as (number of charge/recharge cycles) due to morphology regulation.
- Assess material systems improvements for corrosion resistant materials such as galvanic corrosion and corrosion fatigue due to morphology regulation.
- Achieve simultaneous production of four human macronutrients in microbial food.
- Demonstrate integration of all component processes required to produce microbial food in the field.
- Demonstrate ability to flavor microbial food.

FY 2022 to FY 2023 Increase/Decrease Statement:

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Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** MS-01 / *MATERIALS SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2021**	**FY 2022**	**FY 2023**
The FY 2023 increase is due to a shift from initial designs to development and demonstration.			
Title: Fundamental Limits ***Description:*** Understanding the Fundamental Limits (i.e., achievable boundaries) of scientific principles, processes and technologies is critical to better anticipate technological surprise for our adversaries and ourselves. This thrust explores boundaries across fields such as physics, chemistry, mathematics, biology, and engineering to address critical questions for national security, addressing foundational theory and approaches that include, for example, the fundamental limitations of optical technologies, potential implications for basic biology on national security, and the ability for modeling and simulation to provide a better understanding of complex systems. ***FY 2022 Plans:*** - Replicate ionospheric total electron content signatures caused by meteorological and geophysical transient disturbances using next generation modeling and simulation. - Discover and characterize the nature of atmospheric background conditions through experimental campaigns in the mesospheric region. - Commence development of new multimodal whole-of-atmosphere sensors to identify atmospheric transient disturbances produced by meteorological and geophysical sources. - Demonstrate improved sensitivity of atomic vapor-based electric field sensors in the millimeter wave frequency range. - Demonstrate an atomic vapor cell-based vector magnetometer with improved sensitivity and accuracy in a reduced physics package size. - Demonstrate the potential for improving the atom-photon interaction strength and quantum coherence of vapor quantum devices. - Identify DoD relevant applications for room temperature, vapor cell-based electric and magnetic field sensors and quantum atom-light interfaces. ***FY 2023 Plans:*** - Complete development of new multimodal whole-of-atmosphere sensors to identify atmospheric transient disturbances produced by meteorological and geophysical sources. - Demonstrate using the atmosphere as a sensor to discover sources of transient disturbances in real-world conditions relevant to national security. - Continue to improve sensitivity of atomic vapor-based electric and magnetic field sensors. - Continue to increase the atom-photon interaction strength and quantum coherence of vapor-based quantum devices. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects a shift from component development and integration to system demonstration and refinement.	30.103	20.203	19.500
Title: Basic Photon Science	10.060	10.100	13.956

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		**Date:** April 2022
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** MS-01 / *MATERIALS SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2021**	**FY 2022**	**FY 2023**
Description: The Basic Photon Science thrust is examining the fundamental science of photons and their interactions in integrated devices for potential DoD-applications such as communications, signal processing, spectroscopic sensing and imaging. Research efforts will explore development of a complex theoretical framework for maximum information extraction from complex scenes to guide development of new imaging technologies. Work in this thrust will establish the first-principles limits of photon detector performance in a variety of detector technologies to enable better, more sensitive detectors. ***FY 2022 Plans:*** - Characterize measurement hyperdiversity techniques to generate novel sensor designs needed for autonomous ground systems to operate at high speed at night without a detectable signal. - Create initial predictions of the vehicle speeds that are theoretically supported by completely passive infrared sensors in off-road environments. ***FY 2023 Plans:*** - Fabricate novel sensors that use measurement hyperdiversity for passive sensing and range estimation. - Demonstrate stationary ranging in a laboratory setting using ambient thermal radiation. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects a shift from system characterization to fabrication and demonstration.			
Title: Non-Equilibrium Materials ***Description:*** The Non-Equilibrium Materials thrust explored materials and materials structures that acquired novel properties when driven far from equilibrium. Work in this thrust examined the physical underpinnings and applications of these systems in areas of interest to the DoD, including next generation electronics, high-performance computing, and sensing. Efforts included the development of topologically protected excitations in electronic materials and fundamental studies of exotic quantum states of matter in periodically driven solid-state systems.	8.000	-	-
Accomplishments/Planned Programs Subtotals	53.663	40.303	58.356

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency	**Date:** April 2022

Appropriation/Budget Activity	**R-1 Program Element (Number/Name)**	**Project (Number/Name)**
0400 / 1	PE 0601101E / *DEFENSE RESEARCH SCIENCES*	TRS-01 / *TRANSFORMATIVE SCIENCES*

COST ($ in Millions)	Prior Years	FY 2021	FY 2022	FY 2023 Base	FY 2023 OCO	FY 2023 Total	FY 2024	FY 2025	FY 2026	FY 2027	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	-	35.980	28.188	31.265	-	31.265	17.692	8.123	8.123	8.123	-	-

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, and manufacturing. The project integrates these diverse disciplines to eliminate reliance on foreign sources for critical materials, improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens), maintain warfighter health, and improve recovery. This project also includes efforts to create innovative materials of interest to the military, as well as biological platforms for fabrication. This Program Element also supports innovation and robust transition planning in the technology cycle by working with entrepreneurs to increase the likelihood that DARPA-funded technologies take root in the U.S. and provide new capabilities for national defense.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
Title: Biology for Security (BIOSEC)	11.672	9.351	7.535
Description: The Biology for Security (BIOSEC) program seeks to investigate novel approaches to address the DoD need for rapid detection of unknown and/or emerging biological threats from state actors or violent extremist organizations (VEOs). This program will investigate approaches for identifying pathogens based on specific behaviors, or phenotypes, such as niche finding or cell toxicity. Unlike current methods, which rely on a priori knowledge of the pathogen and cannot detect or otherwise analyze unknown threats, this approach will handle scenarios involving engineered or undiscovered bacterial pathogens that do not have known hallmarks. Advances in this area will produce a completely new capability to assess the emergence of pathogens and to detect pathogens that have been specifically engineered to evade detection by traditional methods. Resulting systems may be used to alert deployed military personnel operating around the world to new biothreats, or in response to a U.S.-based discovery, outbreak, or pandemic. ***FY 2022 Plans:*** - Develop isolation and interrogation platforms on sterilized real-world samples spiked with 50-100 different types of bacteria. - Develop algorithms that combine trait scoring for predictive threat identification. - Develop decision tree optimization algorithm and demonstrate increased pipeline efficiency. - Demonstrate ability to map pathogenic traits to single bacteria. ***FY 2023 Plans:*** - Demonstrate integrated platforms that identify pathogens from unknown consortia. - Transition technology to U.S. government partners tasked with preventing or responding to pathogen outbreaks.			

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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 2021	FY 2022	FY 2023
- Complete independent verification and validation (IV&V) analysis of integrated platforms. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 decrease reflects the shift from research and development activities to testing integrated systems on real-world samples in conjunction with transition partners.			
Title: Rapid Healing for Warfighter Injuries ***Description:*** The Rapid Healing for Warfighter Injuries effort is addressing the DoD need for improving warfighter recovery from injury by developing technologies that can accelerate the restoration and repair of complex tissues. This program will develop approaches that combine high-resolution biosensors to track the healing process in real-time with bioactuators to stimulate restoration where and when needed. The primary challenge to achieving this is the lack of a closed-loop interface that can manipulate highly complex signaling pathways in wounds and the developmental interdependencies that scale from cell to tissue. The program will develop new methods to convert dense multi-modal information into the body's native repair processes, and will leverage artificial intelligence to guide the delivery of the signals necessary for healing. Advances from this program will produce bioactuators that can release diverse stimuli with high spatial and temporal resolution, and biosensors that provide the requisite in situ measurement to guide the healing process. ***FY 2022 Plans:*** - Demonstrate biocompatibility, reliable operation of sensors and actuators, and tracking and control of at least two physiological processes in animal models. - Produce an in vivo sensor system that can accurately report the wound state to be delivered to the independent verification and validation (IV&V) team. - Demonstrate that the model predicts the wound stage from in vivo test data with 80% accuracy. - Demonstrate closed-loop control over at least one physiological process. - Demonstrate improved wound healing for one wound healing stage. - Develop an initial integrated model for multi-systems interventions. ***FY 2023 Plans:*** - Integrate sensors and actuators for one physiological process into a single platform. - Demonstrate that predictions made by the machine-learning algorithms occur at therapy-relevant time scales without sacrificing accuracy. - Initiate independent verification and validation (IV&V) of in vivo biocompatibility of integrated systems. - Demonstrate improved wound healing for two stages of wound healing. ***FY 2022 to FY 2023 Increase/Decrease Statement:***	13.430	16.587	20.421

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
The FY 2023 increase reflects conducting in vivo experiments in large animal models, integrating all components into a single platform, and conducting IV&V assessment of the technology.			
Title: Engineered Living Materials (ELM) ***Description:*** The Engineered Living Materials (ELM) program is pursuing new approaches to engineer complex biological systems for enhanced capabilities and functional materials to improve military infrastructure design and logistics, sensors, and platforms. Complex biological materials and systems have unique properties (e.g., controlled porosity, high strength-to-weight ratios, magnetic, optical) not only because of the inherent components but also because of how those components are assembled together across length scales. Engineering biology tools and techniques are now at a stage to pursue the production, organization, and function of biomaterial systems for a variety of improved capabilities. This program is developing underlying technological platforms to enable information-driven assembly of hierarchical biological systems as well as alternate approaches for the advanced development of critical molecules and materials. Advances in this program will impact next-generation material design for optical and electronic applications; military approaches to infrastructure design in austere environments; as well as established methods for the manufacture and maintenance of military platforms. ***FY 2022 Plans:*** - Characterize biological and mechanical properties of material for durability and reliability under various operational scenarios. - Investigate methods to develop alternate approaches to produce critical molecules and materials for use in austere environments. - Exploit microbial processes and biomolecules to control the incorporation of rare earth elements (REEs) into inorganic materials with magnetic and optical characteristics. ***FY 2023 Plans:*** - Demonstrate methods for alternate approaches to identify, engineer, and develop critical molecules and materials for use in austere environments. - Engineer biological systems that predictably control the composition, size, and architecture of REE-containing nanoparticles that exhibit optical and magnetic properties. ***FY 2022 to FY 2023 Increase/Decrease Statement:*** The FY 2023 increase reflects development in technologies to advance development of critical molecules and materials in austere environments.	2.200	2.250	3.309
Title: Social Simulation (SocialSim) ***Description:*** The Social Simulation (SocialSim) program developed computational models to simulate the future spread and evolution of information in the online environment including multiple global and regional social media platforms. The global	8.678	-	-

Exhibit R-2A, RDT&E Project Justification: PB 2023 Defense Advanced Research Projects Agency		Date: April 2022
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2021	FY 2022	FY 2023
information environment is radically changing how and at what rate information spreads and evolves. Both nation-state and sub-state actors are incorporating messaging into their operations to great advantage. Existing approaches to modeling online information spread have been narrow in scope and focused on keywords or social networks. SocialSim combined models of holistic platform activity with models of anonymized users and networks to capture social media engagement and spread for better simulation and understanding of how information spreads through various platforms and is impacted by events in the real world. This capability will support assessment and prediction of adversary or U.S. information campaign spread and development of realistic, synthetic social media for training and other purposes.			
Accomplishments/Planned Programs Subtotals	35.980	28.188	31.265

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A