Exhibit R-2, **RDT&E Budget Item Justification:** PB 2022 Defense Advanced Research Projects Agency	**Date:** May 2021
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 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total	FY 2023	FY 2024	FY 2025	FY 2026	Cost To Complete	Total Cost
Total Program Element	-	427.837	474.158	395.781	-	395.781	-	-	-	-	-	-
CCS-02: *MATH AND COMPUTER SCIENCES*	-	248.978	285.803	265.784	-	265.784	-	-	-	-	-	-
ES-01: *ELECTRONIC SCIENCES*	-	30.393	35.801	16.361	-	16.361	-	-	-	-	-	-
ES-02: *BEYOND SCALING SCIENCES*	-	62.828	59.025	45.145	-	45.145	-	-	-	-	-	-
MS-01: *MATERIALS SCIENCES*	-	41.584	52.560	40.303	-	40.303	-	-	-	-	-	-
TRS-01: *TRANSFORMATIVE SCIENCES*	-	44.054	40.969	28.188	-	28.188	-	-	-	-	-	-

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 computational social science, artificial intelligence, machine learning and reasoning, data science, complex systems modeling and simulation, and theory of computation. 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 progress 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;

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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 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 (e.g., self-healing materials).

B. Program Change Summary ($ in Millions)	FY 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total
Previous President's Budget	432.284	479.958	415.112	-	415.112
Current President's Budget	427.837	474.158	395.781	-	395.781
Total Adjustments	-4.447	-5.800	-19.331	-	-19.331
• Congressional General Reductions	0.000	-13.800			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.304	8.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-0.751	0.000			
• SBIR/STTR Transfer	-4.000	0.000			
• TotalOtherAdjustments	-	-	-19.331	-	-19.331

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Congressional Add Details ($ in Millions, and Includes General Reductions)	**FY 2020**	**FY 2021**
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 Subtotals for Project: CCS-02	-	8.000
Congressional Add Totals for all Projects	-	8.000

Change Summary Explanation

FY 2020: Decrease reflects the SBIR/STTR transfer and reprogrammings offset by COVID response CARES Act add.
FY 2021: Decrease reflects congressional adjustments.
FY 2022: Decrease reflects completion of the Advanced Tools for Modeling and Simulation, Communicating With Computers, Complex Hybrid Systems, Magnetic Miniaturized and Monolithically Integrated Components (M3IC), A MEchanically Based Antenna (AMEBA), Engineered Living Materials (ELM), and Social Simulation (SocialSim) basic research programs in FY 2021.

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		**Date:** May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** CCS-02 / *MATH AND COMPUTER SCIENCES*

COST ($ in Millions)	Prior Years	FY 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total	FY 2023	FY 2024	FY 2025	FY 2026	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	-	248.978	285.803	265.784	-	265.784	-	-	-	-	-	-

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 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, 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. This Project includes FY 2020 CARES Act funding in the amount of $.304 million for AI models to rapidly screen, prioritize and test Food and Drug Administration (FDA)-approved therapeutics for new COVID-19 drug candidates.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
Title: Foundational Artificial Intelligence (AI) Science ***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 embed known physics, mathematics, and other prior knowledge to improve performance of AI systems, particularly for problem sets involving incomplete, sparse, and noisy data. 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, and other DoD relevant applications. ***FY 2021 Plans:*** - Develop automated approaches to extract data from electronic lab notebooks, tables, and figures. - Build and demonstrate property prediction models which are informed by and guide automated experimental platforms. - Develop introspective AI systems that are capable of expressing task competencies based on experiences, learned task rules and rule dependencies.	64.845	58.845	58.050

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Demonstrate competency-aware machine learning behaviors and capabilities in machine learning applications. - Develop novelty generators and novelty-robust AI techniques to identify rapidly and respond appropriately to new relationships, representations, and capabilities. - Begin to evaluate novelty generators and novelty-robust AI techniques compared to non-robust methods performing on known tasks. - Demonstrate, in modeling and simulation, non-Von Neumann devices and circuits that have significant benefits over classical computers. - Develop AI-aided capabilities for recovering symbolic mathematical formulas from binary code alone and, more generally, for mathematical comprehension of complex software. - Develop and implement computationally feasible cryptographic techniques for securing the information exchange transactions implicit to cooperative training of Machine Learning (ML) models, and demonstrate their ability to preserve privacy when attacked by a sophisticated adversary. - Develop approaches to automatically identify signatures for the tools used by an adversary in information deception attacks in order to attribute attacks and aid in the formulation of defensive measures. - Develop and apply symbolic and statistical AI techniques to understand collaborative 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. - Assess human pneumothorax ultrasound datasets for AI model training. - Continue efforts to explore frontiers in Artificial Intelligence with a focus on third wave AI. ***FY 2022 Plans:*** - Continue development of novelty generators and novelty-robust AI techniques to include new environments, goals, and context. - Develop methods to accurately correlate data across multiple sources, such as lab notebooks, tables, figures, and experimental databases. - 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. - Develop capabilities for AI systems to learn to compliment and coordinate with humans. Demonstrate potential for enhanced human-machine teaming performance. - 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. - Demonstrate the accuracy of AI models for pneumothorax classification on a portable device.			

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Continue efforts to explore frontiers in Artificial Intelligence with a focus on third wave AI. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects minor program repricing.			
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 2021 Plans:*** - Complete design of a new scheme capable of coherent control of each individual qubit in a Penning ion trap for ion based quantum computing. - Identify families of instances where near term quantum computers can outperform classical computing in the optimization of complex systems. - Initiate efforts to quantify the speedup achievable with near term quantum computers over classical computing for the optimization of complex systems. - Develop methods for benchmarking quantum processors. - Initiate development of a network architecture that achieves resilience through closed-loop control based on in-network telemetry and verified code executing at line rates on programmable hardware. ***FY 2022 Plans:*** - Demonstrate the use of a near term quantum computer for the optimization of complex systems. - 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.	15.580	24.000	36.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Initiate development of scalable testing techniques for measuring progress in quantum information processing towards addressing specific, transformational computational challenges. - 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 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase is due to a shift from design and planning to demonstration.			
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 2021 Plans:*** - Enhance core cognitive models with additional capabilities, such as spatial navigation at the cognitive developmental level of nine- to twelve-month old infants, and evaluate model performance on prediction tasks. - Develop core cognitive models with initial experience learning capabilities, and evaluate model performance against experience learning tasks. - Modify the simulation environment for evaluation of additional machine learning methods, cognitive capabilities, prediction tasks, and experience learning tasks. - Enhance common knowledge services to handle common sense phenomena of increased complexity, and assess performance of services against benchmark common sense challenge problem suites. ***FY 2022 Plans:*** - Develop core cognitive models with enhanced experience learning capabilities, and evaluate model performance against experience learning tasks requiring elements of intuitive physics, navigation, and models of intentional agents. - Enhance core cognitive models with additional capabilities, such as models of intentional agents used by twelve- to eighteen-month old infants, and evaluate model performance on prediction tasks.	12.375	16.500	18.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Augment the simulation environment to enable evaluation of additional machine learning methods, cognitive capabilities, prediction tasks, and experience learning tasks, particularly for problems that require sensemaking, human-machine collaboration, or knowledge transfer. - Enhance common knowledge services to handle common sense phenomena of increased complexity, and assess performance on benchmark common sense challenge problem suites in environments with greater complexity, noise, and novelty. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects continued development of machine common sense technologies and the simulation environment, and additional work to refine techniques and assess of performance against benchmark commonsense 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. Techniques developed under the GARD program will address the current limitations of defenses and produce ML and AI systems suitable for use in adversarial environments. ***FY 2021 Plans:*** - Develop a general framework for deception and related attacks on ML, and quantify the vulnerability of ML algorithm classes to an adaptive adversary. - Develop defenses that leverage multiple data sources to reduce vulnerability to adversarial inputs. - Extend evaluation framework for testing ML defenses for multi-sensor scenarios, and evaluate ML defenses in such scenarios. ***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 scenarios, and implement and test ML defenses for use against an AI-enabled adversary. ***FY 2021 to FY 2022 Increase/Decrease Statement:***	14.000	15.400	17.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
The FY 2022 increase reflects continued development of ML defenses and an ML defense evaluation framework, and additional work to evaluate the effectiveness of ML defensive techniques against an AI-enabled adversary.			
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 2021 Plans:*** - Award new FY 2021 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 2020 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 2019 participants to refine technology further and align to 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. - Award Director's Fellowships for top FY 2020 participants to refine technology further and align to DoD needs.	17.000	17.000	17.000
Title: Human Social Systems ***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,	17.500	26.250	15.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
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 2021 Plans:*** - Refine, implement, and test algorithms for systematically assigning quantitative confidence scores to social and behavioral science research with focus on logically complete methods that scale broadly across the social science research domain. - Demonstrate interactive meta-analytical algorithmic approaches to quantify social and behavioral science research that situates individual claims within the larger corpus of social science supporting broad generalizability appropriate for decision makers. - Increase efficiency and reduce cost of simulated predictive market algorithms for automatically assigning quantitative confidence scores to social and behavioral science researchers to support more rigorous and reproducible social and behavioral science. - Begin development of methods to semi-automatically create causal understanding of local systems with from participatory modeling with local populations. - Build evidence that cognitive models can be created with a scalable number of touch points. ***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. - Demonstrate improved prediction accuracy from developed causal models compared to current methods. - 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.			

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Explore external and internal validity of social influence metrics within testbed. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects a shift from development to demonstration.			
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 skills 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 a team. 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 2021 Plans:*** - Investigate and derive performance predictions for computational agents capable of advising and guiding humans in the performance of complex cognitive and physical tasks. - Develop prototype agents that exhibit machine theory of mind and the ability to contribute to effective human teams. - Enhance virtual testbed and test prototype agents that exhibit machine theory of mind on diverse models of human and human-machine interaction. ***FY 2022 Plans:*** - Demonstrate and test prototype 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 2021 to FY 2022 Increase/Decrease Statement:***	13.060	17.000	15.000

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2020**	**FY 2021**	**FY 2022**
The FY 2022 decrease reflects ramping down of efforts to develop software agents that exhibit machine theory of mind, and focus shifting to experimentation to quantify factors that influence the performance of computational agents and human-machine teams.			
Title: Safe Documents (SafeDocs) ***Description:*** The Safe Documents (SafeDocs) program is developing software technologies that constrain syntactic complexity in data 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 documents and streaming data greatly increases the computational attack surface. The SafeDocs program is focused on rationalizing existing data formats, with attention to compatibility, and advancing the state of the art in the security of document and data format parsers. SafeDocs advances are essential to enabling automated code verification, assuring that the conditions of data validity are enforced, and securing documents and streaming data. ***FY 2021 Plans:*** - Create a safe subset for a very widely used electronic data document format, and show that it supports the same essential functionality as the legacy standard specification. - Construct a program to convert a large majority of legacy format documents to safe format without loss of essential content, and show that the content produced by the program is secure against maliciously crafted data. - Demonstrate the ability to reduce common instances of streaming data formats to safe, simplified subsets that allow the same essential functionality under resource constraints representative of an embedded system. ***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 bidirectional machine-readable feedback mechanisms from verification tools to improve system automation. - Automate testing methodologies for a large code base, and demonstrate safe parser construction using the developed tools. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 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 of techniques in representative systems.	12.900	16.500	12.000
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	8.000	15.000	12.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
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. 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 2021 Plans:*** - Develop approaches to label reduction via automated transfer learning that discovers similar problems and learns what is important for a given task. - Develop theoretical limits for transfer learning for problem classes and domains of interest to DoD. - Demonstrate the capability of new ML algorithms to learn with orders of magnitude reduction in labeled data on problems relevant to the DoD. ***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 and domains with datasets relevant to the DoD. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects reduced development of ML techniques that require less labeled data for effective training, and focus shifting to optimization and demonstration of techniques on datasets relevant to the DoD.			
Title: World Modelers ***Description:*** The World Modelers program is creating explanatory models for 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 2021 Plans:***	16.300	13.700	12.000

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
- Refine models of acute, high-impact phenomena such as natural disasters that disrupt civilian infrastructure to enable ensemble forecasting and estimation of uncertainty. - Extend technologies to accommodate more complex perturbations and apply to additional use cases such as disease outbreak. - Perform evaluations incorporating new data sources, models, and factors for a diverse set of transition partners. ***FY 2022 Plans:*** - Integrate software capabilities applicable to the diverse data and modeling tasks encountered in high-priority use cases. - Optimize techniques in response to transition partner feedback. - Harden technologies and perform evaluations in collaboration with transition partners. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects conclusion of efforts to develop models for acute high-impact phenomena, and focus shifting to hardening and evaluation of technologies in collaboration with transition partners.			
Title: Perceptually-Enabled Task Guidance (PTG)* ***Description:*** *Formerly Application-Tailored Artificial Intelligence (APTAI) The Perceptually-Enabled Task Guidance (PTG) program will develop artificial intelligence (AI) technology that guides users in the performance of a wide range of cognitively challenging physical tasks. PTG will leverage 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 would enable mechanics, medics, and other specialists to perform tasks within and beyond their skillsets with greater accuracy and efficiency. ***FY 2021 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. - 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. ***FY 2022 Plans:***	-	7.000	13.234

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** CCS-02 / *MATH AND COMPUTER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- 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. - Identify and collaborate with military stakeholders on high-priority task use cases, potentially involving repair of mechanical, electrical, or electronic systems or emergency medical care, for demonstration and evaluation of integrated perceptual agent prototype systems. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects continued effort to develop foundational techniques for perceptually-enabled intelligent agents and increased efforts to integrate the techniques for application to high-priority task use cases.			
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 2021 Plans:*** - Explore novel AI tools with potential to effectively elicit and impart acquired knowledge precisely when useful and applicable via user friendly interfaces. - Demonstrate fine grain knowledge acquisition and dissemination using question and answering system. - Develop novel AI tools capable of recognizing and representing implicit and explicit context of human tasks. ***FY 2022 Plans:***	-	6.000	10.000

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** CCS-02 / *MATH AND COMPUTER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- 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. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects a shift from proof of concept demonstrations to system design and development.			
Title: Analyzing Software to Protect against Evolving Cyber Threats (ASPECT)* ***Description:*** *Formerly Formal Methods at Scale (FMaS) The Analyzing Software to Protect against Evolving Cyber Threats (ASPECT) program will develop 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 develop technologies for querying 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. One major impact sought by ASPECT is the capability to efficiently and reliably find all semantically equivalent instances of a vulnerability, as such a capability would make the information that resides in vulnerability databases far more useful to software developers and certifiers. ***FY 2021 Plans:*** - Explore methods to analyze and query codebases across multiple dimensions for the presence or absence of semantic features. - Formulate approaches for querying codebases in a language-agnostic manner while also providing quantifiable metrics of analyzability to drive software improvements. ***FY 2022 Plans:*** - Build automated tools to model vulnerabilities in a manner that protects sensitive intellectual property while allowing for discovered patterns of vulnerability to be searched for in other codebases.	-	4.000	8.500

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Develop language-agnostic metrics of software quality and evidence management techniques that provide actionable or otherwise useful information for software developers. - Assess the code query and quality measurement capabilities of the tools and demonstrate the capability to identify latent known vulnerabilities including syntactically-distinct but semantically-equivalent instances. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects continued development of techniques and tools to analyze and query codebases and the addition of efforts to assess and demonstrate the capability to identify vulnerabilities including syntactically-distinct but semantically-equivalent instances.			
Title: Agile Artificial Intelligence (AgAI) ***Description:*** The Agile Artificial Intelligence (AgAI) program aims to create capability to rapidly stand-up AI capabilities 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 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 the developed 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. - 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 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects program initiation.	-	-	21.000
Title: Synergistic Discovery and Design (SD2)	17.000	16.000	-

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** CCS-02 / *MATH AND COMPUTER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
Description: The Synergistic Discovery and Design (SD2) program is developing 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 will collect raw experimental data into a data and analysis hub, develop computational techniques that extract scientific knowledge directly from experimental data, and create 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. ***FY 2021 Plans:*** - Test design and discovery tools in supporting a design-test-build cycle to rapidly produce protein therapeutics, biosensors, and stable solar materials, and demonstrate automated experimental loops that provide rapid improvement in experimental performance. - Develop models of underlying scientific principles for domains such as complex systems design, biosynthesis, computational social science, and information operations. - Extend software to integrate data, experimental protocols, and analysis methods from diverse research groups, and identify resilience strategies for automated experimental bio-cyber-physical laboratories. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects program completion.			
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 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.	19.700	10.765	-

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** CCS-02 / *MATH AND COMPUTER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2020**	**FY 2021**	**FY 2022**
FY 2021 Plans: - Integrate and evaluate math and algorithms to generate multi-physics simulators into current simulation processes to assess utility against DoD challenges. - Explore the potential for achieving multi-basis imaging techniques that do not require active illumination. - Utilize image models to understand fundamental tradeoffs in data acquisition, prior knowledge and information resolution. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects program completion.			
Title: Communicating With Computers (CWC) ***Description:*** The Communicating With Computers (CWC) program is advancing human-computer interaction by enabling computers to comprehend language, gesture, facial expression, and other communicative modalities in context. 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 aims 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 will apply and extend research in language, vision, gesture recognition and interpretation, dialog management, cognitive linguistics, and the psychology of visual encoding. CWC also aims to extend the communication techniques developed for physical contexts to nonphysical contexts and virtual constructs. ***FY 2021 Plans:*** - Perform final human-computer interaction technology evaluations on multiple program use cases. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects program completion.	10.000	6.543	-
Title: Complex Hybrid Systems ***Description:*** The Complex Hybrid Systems program is 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 thrust will better enable the systematic design of complex hybrid systems that can achieve unprecedented resilience and adaptability in unexpected environments. ***FY 2021 Plans:*** - Characterize hybrid team performance using at least two different mediation approaches.	10.718	7.300	-

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Characterize dynamics and overall team performance with respect to changes in a single environmental factor. - Implement AI-enabled dynamic mediation scheme and characterize team performance using this scheme. - Demonstrate a static and dynamic AI-mediated mechanism or policy for hybrid teams and characterize impact on team performance in response to environmental change. - Develop and demonstrate techniques and tools for model contextualization, understanding, and comparison, and for rapid automatic construction of executable models from literature sources. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease is due to program completion.			
Accomplishments/Planned Programs Subtotals	248.978	277.803	265.784

	FY 2020	FY 2021
Congressional Add: Foundational Artificial Intelligence - Congressional Add ***FY 2021 Plans:*** Conduct research in Foundational Artificial Intelligence.	-	5.000
Congressional Add: Alternative Computing - Congressional Add ***FY 2021 Plans:*** Conduct research in Alternative Computing.	-	3.000
Congressional Adds Subtotals	-	8.000

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		**Date:** May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCI ENCES*	**Project (Number/Name)** ES-01 / *ELECTRONIC SCIENCES*

COST ($ in Millions)	Prior Years	FY 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total	FY 2023	FY 2024	FY 2025	FY 2026	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	-	30.393	35.801	16.361	-	16.361	-	-	-	-	-	-

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 progress 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 2020	FY 2021	FY 2022
Title: Atomic-Photonic Integration (A-PhI)	14.000	17.000	9.361
Description: The Atomic-Photonic Integration (A-PhI) program is reducing the complexity of atomic clocks and gyroscopes by using integrated photonics for position, navigation, and timing (PNT) applications. 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 are usually 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. Currently, in the absence of GPS, tactical grade clocks and tactical/ navigation grade Inertial Measurement Units can provide GPS-like accuracy for the short term. However, longer-term GPS independent strategies are still desirable. A-PhI will enable long-term GPS independence and enable PNT accuracy better than GPS for short durations. ***FY 2021 Plans:*** - Demonstrate an atomic clock in an integrated photonic integrated circuit physics package. - Perform critical design of a trapped atomic gyroscope. - Demonstrate a photonic integrated chip capable of atom trapping and cooling compatible with proposed clock architecture. ***FY 2022 Plans:*** - Demonstrate an atomic clock physics package meeting size, frequency stability, and phase noise metrics.			

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		**Date:** May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-01 / *ELECTRONIC SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2020**	**FY 2021**	**FY 2022**
- Demonstrate a trapped atom gyroscope with single measurement angle rate resolution and scale factor exceeding commercial gyroscopes. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects a shift from fabrication to technology demonstration.			
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, color (wavelength) of light emission, and 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 need for 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/or n-type doping. ***FY 2021 Plans:*** - Characterize low-defect density substrates and investigate epitaxial material growth. - Develop theoretical models of high-energy performance and avalanche breakdown in UWBG materials. ***FY 2022 Plans:*** - Characterize low-energy heterogeneous epitaxially-grown UWBG devices. - Refine theoretical models with experimental verification of high-energy performance and avalanche breakdown in UWBG materials. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects minor program repricing.	-	6.801	7.000
Title: Magnetic Miniaturized and Monolithically Integrated Components (M3IC) ***Description:*** The Magnetic Miniaturized and Monolithically Integrated Components (M3IC) program aims to integrate magnetic components onto semiconductor materials, improving the size and functionality of Electromagnetic (EM) systems for communications, radar, and electronic warfare (EW). Current EM systems use magnetic components such as circulators, inductors, and isolators that are bulky and cannot be integrated with electronic circuitry. This limits the utility of the magnetic components as well as their ability to impact overall system performance and function. Reducing the size, weight, and power of	7.053	7.000	-

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
magnetic components and integrating them onto semiconductor chips, however, could provide new mechanisms for the control and manipulation of EM signals as well as enable broader exploitation of magnetic materials. For instance, tighter integration could yield smaller radar systems, higher bandwidth communication over longer ranges, improved jam resistance, and more resilient EW systems. The M3IC program is divided into three technical areas: integration of magnetic materials and systems with semiconductor technology; accurate and efficient modeling of magnetic phenomena from the molecular to the component system level; and exploitation of magnetic phenomena in innovative component designs relevant to DoD EM systems. ***FY 2021 Plans:*** - Implement and optimize micro-magnetic codes and validate circuit models in industry-standard radio frequency circuit design tools. - Demonstrate improved performance of integrated miniature components by utilizing design tools developed in the M3IC program. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects program completion.			
Title: A MEchanically Based Antenna (AMEBA) ***Description:*** The A MEchanically Based Antenna (AMEBA) program seeks to develop 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. For classical antennas, the minimum antenna size for efficient transmission is related to the wavelength of the RF signal. This fundamental property prevents reducing the size of today's ULF and VLF transmitting antennas, which can be up to a mile in length. Whereas traditional antennas generate electromagnetic waves by driving current through a conductive material, AMEBA takes a novel approach, mechanically moving an electrical charge or magnet to generate electromagnetic waves at ULF and VLF. This mechanical coupling provides unique advantages over traditional approaches at these frequencies, most notably a greater than 1,000-fold reduction in antenna size. AMEBA will focus on developing both the materials and precision-controlled electromechanical systems required for an efficient transmitter system. This new capability would enable 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. ***FY 2021 Plans:*** - Demonstrate high-efficiency mechanical modulation techniques. ***FY 2021 to FY 2022 Increase/Decrease Statement:***	5.990	5.000	-

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-01 / *ELECTRONIC SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
The FY 2022 decrease reflects program completion.			
Title: SHort Range Independent Microrobotics Program (SHRIMP) ***Description:*** The SHort Range Independent Microrobotic Platforms (SHRIMP) program developed efficient and capable actuation mechanisms and power efficient voltage conversion circuits for microrobotic platforms. The primary technical focus areas were the efficiency, robustness, and force output of millimeter-scale actuators, and the power and energy capacity of batteries and chip-level power converters. The program advanced the microrobotics field, allowing future robots to be realized in much smaller form factors than are previously possible. A companion applied research effort was funded in PE 0602716E, Project ELT-01.	3.350	-	-
Accomplishments/Planned Programs Subtotals	30.393	35.801	16.361

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		**Date:** May 2021
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 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total	FY 2023	FY 2024	FY 2025	FY 2026	Cost To Complete	Total Cost
ES-02: *BEYOND SCALING SCIENCES*	-	62.828	59.025	45.145	-	45.145	-	-	-	-	-	-

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 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.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
Title: Beyond Scaling - Materials	10.000	11.000	8.000
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 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, innovative processes to vertically integrate these materials with others to realize superior computational mechanisms, and cryogenic computing for 10X improvement in electricity cost or performance. Applied research for this program is funded within PE 0602716E, Project ELT-02. ***FY 2021 Plans:*** - Test memory elements supporting in-memory computation and stochastic computing. - Emulate and design functioning prototype to demonstrate system performance benefit of new computational circuit topologies. - Initiate new memory hardware studies to validate DoD-relevant applications and benefit of program approach. ***FY 2022 Plans:*** - Demonstrate energy efficient in-memory computing processing units with high energy efficiency per operation. - Design and implement advanced compute units for advanced DoD relevant machine learning applications. - Simulate and analyze transistor, memory, and interconnect performance at low temperature for low temperature circuit designs. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects the program transitioning to final demonstrations.			
Title: Beyond Scaling - Architectures and Designs	15.000	14.000	13.645

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
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 scaling in silicon transistors (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. The program also explores architecture options for physically protecting sensitive information. Advances under this program will 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 2021 Plans:*** - Extend research and development of high level languages and novel modeling techniques while reducing transaction overhead on embedded devices. - Collect and curate training data for chip-level layout from published journals to create design tools using machine learning techniques. - Improve accuracy and speed of machine learning based algorithms for chip, package, and board design through incorporation of additional data. ***FY 2022 Plans:*** - Fabricate and test automatically generated digital and analog integrated circuits created using program-developed open source software tools. - Demonstrate the implementation of novel provably secure hardware, with computation overheads that are practical for real-world use. - Develop specialized machine designed hardware, and benchmark against general purpose machine learning chips. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects minor program repricing.			
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, meaning that they have difficulty accounting for in-the-field mission changes or for unexpected deviations in the data being processed. To overcome this limitation, L2M will pursue learning approaches inspired by biological systems,	19.828	16.025	5.500

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
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 2021 Plans:*** - Refine the first set of algorithms on the common cross-performer test cases, and add new algorithms to the test cases. - Integrate multiple L2M capabilities into complete systems. - Demonstrate complete set of L2M capabilities. - Evaluate contribution of individual components to L2M capabilities. - Study safety and security in L2M systems. ***FY 2022 Plans:*** - Demonstrate integrated L2M systems in multiple domains. - Transition L2M algorithms into selected applications. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects the shift from integration to demonstration of the L2M system.			
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 2021 Plans:*** - Demonstrate promising materials, power efficient RF, THz, digital, and storage devices prototypes.	18.000	18.000	18.000

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
- Explore next-generation distributed and centralized computing architectures and subsystems to enhance efficiency of information extraction, processing, and autonomous control. - Establish additional multidisciplinary projects across academic research teams to enrich their research agenda for future microsystems. ***FY 2022 Plans:*** - Advance materials, power efficient RF, THz, digital, and storage devices for technology adoption or transition. - Demonstrate next-generation distributed and centralized computing architectures and subsystems with enhanced efficiency of information extraction, processing, and autonomous control.			
Accomplishments/Planned Programs Subtotals	62.828	59.025	45.145

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total	FY 2023	FY 2024	FY 2025	FY 2026	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	-	41.584	52.560	40.303	-	40.303	-	-	-	-	-	-

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 2020	FY 2021	FY 2022
Title: Molecular Systems and Materials Assembly	7.000	5.500	5.300
Description: The Molecular Systems and Materials Assembly thrust is exploring new approaches for the synthesis, assembly, and characterization of molecules and materials 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 therapeutics, energetics, computation and next generation optical materials. Specific approaches include non-traditional synthetic approaches such as the use of extreme pressure and/or temperature conditions, engineering and controlling atomic-scale processing routes for designer microstructures, and the synthesis and rapid screening of many molecules to more quickly identify those with desired functions and/or properties. Efforts in this thrust also include assembly of these and other materials, such as subwavelength engineered shapes, into micro-to-macro-scale objects and devices, exploration of molecules for information storage and processing, and fundamental studies of the properties and function of these molecular ensembles and systems. ***FY 2021 Plans:*** - Establish projections for data access speeds of molecular storage methods with fully automated workflows. - Provide necessary design modifications to molecular computing systems to further improve input/output (I/O) rate, data read error, and computational accuracy. ***FY 2022 Plans:*** - Assess novel approaches to sensing, signal processing, computation, actuation, and energy storage such as structural ionic systems. - Investigate new structural actuation mechanisms such as electrochemical intercalation with combined actuation capability and structural strength and stiffness. - Explore robust local energy harvesting techniques with high structural capability and minimal parasitic mass. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease is due to minor program repricing.			
Title: Fundamental Limits	13.000	19.000	18.903

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
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. This thrust is 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 2021 Plans:*** - Complete Engineered Materials Challenge Problems and transition to Government partners. - Demonstrate in simulation the ability of multi-physics models to predict atmospheric perturbations, such as plasma "holes" and acoustic shock waves, associated with small scale meteorological phenomena. - Investigate external modulation of bacteria (biofilm) Radio Frequency (RF) channels, for potential maritime applications; solidify RF channel models via modeling and measurements. - Use experimental methods and parametric models to develop devices that meet challenge problem objectives in the areas of extreme nonlinearities, thermal engineering, and disruptive electrodynamics. - Identify new approaches to improve the range and sensitivity of atmospheric measurements to enable routine characterization of the mesosphere. - Design vapor cell-based vector magnetometers with improved sensitivity and accuracy in a small physics package. - Investigate techniques for improving the sensitivity and reducing the instantaneous bandwidth of vapor cell-based electric field sensors in the mmW frequency range. ***FY 2022 Plans:*** - Experimentally demonstrate challenge problem objectives in areas of extreme nonlinearities, thermal engineering, and disruptive electrodynamics. - 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. - Develop 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 mmW 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.			

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
- Identify DoD relevant applications for room temperature, vapor cell-based electric and magnetic field sensors and quantum atom-light interfaces. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease is due to minor program repricing.			
Title: Non-Equilibrium Materials ***Description:*** The Non-Equilibrium Materials thrust is exploring materials and materials structures that acquire novel properties when driven far from equilibrium. Work in this thrust will examine 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 will include the development of topologically protected excitations in electronic materials and fundamental studies of exotic quantum states of matter in periodically driven solid-state systems. ***FY 2021 Plans:*** - Apply advanced metrology for high-resolution space and time-resolved spin-textures to observe topological spin structures. - Implement braiding operations in topologically protected qubits. - Demonstrate proof of principle topological memory device. - Engage with industry to determine path for implementing topological protection in memory and logic. - Demonstrate many-body localization and increased quantum coherence time to enable high-fidelity multi-qubit logic gates in spin-based quantum information processors. - Advance metrology, particularly atomic clocks, beyond the standard quantum limit via entangled quantum matter stabilization. - Optimize the performance of nitrogen-vacancy diamond-based solid-state magnetometers by improving their optical readout and control protocols. - Demonstrate phase noise reduction and efficiency enhancement in terahertz optical signal generation using microresonator-based Kerr frequency combs (soliton microcombs). ***FY 2022 Plans:*** - Apply developed metrology to skyrmion-host materials. - Test prototype devices for topologically protected memory. - Demonstrate inertial sensors with increased angular sensitivity and bias stability using quantum gyroscopes. - Demonstrate improved multi-qubit logic gate fidelities using engineered periodic control pulses in a highly scalable quantum dot architecture for quantum computing. - Demonstrate overall enhancements in magnetic, temperature, and rotation sensitivities of solid-state quantum sensors by using time-dependent periodic drives. ***FY 2021 to FY 2022 Increase/Decrease Statement:***	15.450	16.000	4.000

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		**Date:** May 2021
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 2020**	**FY 2021**	**FY 2022**
The FY 2022 decrease is due to transition from development to demonstration.			
Title: Basic Photon Science ***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. One focus area is development of novel, chip-scale optical frequency comb sources and associated technologies for spectroscopic sensing, identification, and quantification of multiple trace materials in spectrally cluttered backgrounds. Additional research 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 2021 Plans:*** - Explore new fundamental techniques with potential to create measurement hyperdiversity. - Develop and demonstrate imaging models to understand fundamental tradeoffs in information gathering and 3-dimensional resolution. ***FY 2022 Plans:*** - Characterize measurement hyperdiversity techniques to generate novel sensor designs. - Create initial predictions of the vehicle speeds that are theoretically supported by completely passive infrared sensors in off-road environments. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase is due to minor program repricing.	6.134	12.060	12.100
Accomplishments/Planned Programs Subtotals	41.584	52.560	40.303

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		**Date:** May 2021
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

COST ($ in Millions)	Prior Years	FY 2020	FY 2021	FY 2022 Base	FY 2022 OCO	FY 2022 Total	FY 2023	FY 2024	FY 2025	FY 2026	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	-	44.054	40.969	28.188	-	28.188	-	-	-	-	-	-

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 (e.g., self-healing, optoelectronic or magnetic materials), 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 2020	FY 2021	FY 2022
Title: Biology for Security (BIOSEC)	9.855	11.172	11.601
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 2021 Plans:*** - Perform continued platform integration for combined bacterial processing for isolation, integration, and data collection. - Increase isolation and interrogation on complex samples that simulate real environments. - Demonstrate the ability to combine bacterial phenotypes and single-cell omics to support pathogenic trait mapping. - Validate increased algorithmic performance on predicting pathogenicity of unknown bacteria. ***FY 2022 Plans:*** - Develop isolation and interrogation platforms on sterilized real world samples spiked with 50-100 different types of bacteria.			

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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 2020	FY 2021	FY 2022
- 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 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 increase reflects minor program repricing.			
Title: Rapid Healing for Warfighter Injuries* ***Description:*** *Formerly Native Bioelectronic Interfaces 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 2021 Plans:*** - Incorporate validated sensing data into models and algorithms. - Demonstrate biocompatibility, reliable operation of actuators, and control of at least two physiological processes in animal models. - Demonstrate biocompatibility, reliable operation of sensors, and tracking of at least two physiological processes in animal models. - Demonstrate that the algorithmic model is both descriptive and able to determine the current stage of healing from acquired sensor data. ***FY 2022 Plans:*** - 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.	12.116	17.244	16.587

B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Develop an initial integrated model for multi-systems interventions. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects minor program repricing.			
Title: Social Simulation (SocialSim) ***Description:*** The Social Simulation (SocialSim) program is developing a computational capability to simulate the spread and evolution of information in the online environment. The global 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 for understanding online information spread and evolution are largely based on specialized exercises that take considerable time to orchestrate and execute, and have limited accuracy. SocialSim aims to enable a deeper, more quantitative, and better validated understanding of adversaries' messaging campaigns and their likely outcomes, as well as exploration of potential responses. ***FY 2021 Plans:*** - Extend prototype tools using ensemble modeling and meta-modeling techniques, and by incorporating exogenous data sources. - Develop a visualization capability to analyze, assess, and debug the outputs of the multiple simulation models. - Explore the utility of prototype tools for modeling the spread of misinformation/disinformation and for counterfactual simulation in collaboration with operational users. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects program completion.	10.008	9.853	-
Title: Engineered Living Materials (ELM) ***Description:*** The Engineered Living Materials (ELM) program is pursuing new approaches to engineer complex, multi-cellular systems for enhanced capabilities and functional materials to improve military infrastructure design and logistics. Complex biological materials and systems have unique properties (e.g., controlled porosity and high strength-to-weight ratios) 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 organization and function of multi-cellular systems for a new class of improved capabilities. This program is developing underlying technological platforms to enable information-driven assembly of hierarchical multi-cellular systems for the development of advanced materials. Advances in this program will impact military approaches to infrastructure design in austere environments as well as established methods for the manufacture and maintenance of military platforms. ***FY 2021 Plans:*** - Verify stability and scalability of material over a prolonged period under operational conditions.	7.605	2.700	-

Exhibit R-2A, RDT&E Project Justification: PB 2022 Defense Advanced Research Projects Agency		Date: May 2021
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2020	FY 2021	FY 2022
- Pressure test self-healing proficiency for deformation, puncture, and tearing resistance under operational conditions. ***FY 2021 to FY 2022 Increase/Decrease Statement:*** The FY 2022 decrease reflects program completion.			
Title: Biological Complexity (BioCom) ***Description:*** The Biological Complexity (BioCom) program sought to enhance the understanding of the basic processes associated with biological network interactions, communication, and control to enable novel approaches and technology development to improve warfighter readiness and resilience. Key advances delivered from this research included the identification of approaches to create stable, predictable, and dynamic control mechanisms of biological networks. Such information allows the determination of a biosystem's state and enables the prediction of control behavior. Applications range from infectious disease mitigation or prevention, maintaining warfighter health, to leveraging biological systems for optimal production of therapeutics.	4.470	-	-
Accomplishments/Planned Programs Subtotals	44.054	40.969	28.188

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A