ARMY RESEARCH LABORATORY

BROAD AGENCY ANNOUNCEMENT

FOR

BASIC AND APPLIED SCIENTIFIC RESEARCH

W911NF-12-R-0011
15 May 2012 – 31 March 2017

ISSUED BY:

U.S. Army Contracting Command-Aberdeen Proving Ground
Research Triangle Park Division
P. O. BOX 12211
Research Triangle Park, NC 27709-2211

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INTRODUCTION
This Broad Agency Announcement (BAA), which sets forth research areas of interest to the Army Research Laboratory (ARL) Directorates and Army Research Office (ARO), is issued under the paragraph 6.102(d)(2) of the Federal Acquisition Regulation (FAR), which provides for the competitive selection of basic research proposals. Proposals submitted in response to this BAA and selected for award are considered to be the result of full and open competition and in full compliance with the provision of Public Law 98-369, "The Competition in Contracting Act of 1984" and subsequent amendments.

Research proposals are sought from educational institutions, nonprofit organizations, and commercial organizations for research in materials sciences; ballistics and aeromechanics sciences; information sciences; human sciences; survivability, lethality, and vulnerability analysis and assessment; chemistry; electronics; physics; environmental sciences; life sciences; mechanical sciences, mathematical sciences, computing sciences and network sciences. Proposals will be evaluated only if they are for scientific study and experimentation directed toward advancing the state of the art or increasing knowledge and understanding.

ARO has primary responsibility for ARL's extramural basic research programs, with specific research interests as described in Part II.A.2. The ARL Directorates, while having primary responsibility for ARL's in-house research programs, also manage select extramural basic research programs. The research interests of the Directorates are described in Part II.A.1. Although ARL Directorates will consider funding proposals for extramural research programs, they can fund only a modest number of proposals in a single fiscal year. It should be noted that the ARL Directorates are highly interested in performing research in collaboration with other scientists and engineers. So, in addition to funding select external research projects, the ARL Directorates also have a strong interest in performing joint research with other organizations in the Directorates' core competency areas as described in this BAA. Inquiries regarding funding and/or collaborations should be directed to the listed Technical Point of Contact (TPOC).

Foreign owned, controlled, or influenced firms are advised that security restrictions may apply that could preclude their participation in these efforts. Before preparing a proposal, such firms are requested to contact the ARL Security and Counterintelligence Branch (301) 394-2444 concerning their eligibility. Pursuant to the policy of FAR 35.017 and supplements, selected Federally Funded Research and Development Centers may propose under this BAA.

PART II, Other Programs, addresses specific contributions to Conferences and Symposia and HBCU/MI support.

The Army has a long history of advocating and supporting research at historically black colleges and universities and minority institutions (HBCU/MI). We actively seek research proposals from HBCUs and MIs in full competition with all offerors who may submit proposals under this BAA. Proposals may be submitted at any time. We also encourage the inclusion of HBCUs and/or MIs as part of a consortium proposal or as subcontractors/ subgrantees to prime recipients.

In order to conserve valuable offeror and Government resources and to facilitate determining whether a proposed research idea meets the guidelines described herein, prospective offerors contemplating submission of a white paper or proposal are strongly encouraged to contact the appropriate technical point of contact (TPOC) before submission. The TPOCs' names, telephone numbers, and e-mail addresses are listed immediately after each research area of interest. If an offeror elects to submit a white paper, it must be prepared in accordance with the instructions contained in PART III Section 3. Upon receipt, a white paper will be evaluated and the offeror shall be advised of the evaluation results. Offerors whose white papers receive a favorable evaluation may be contacted to prepare a complete proposal in accordance with instructions contained in PART III Section 5.

The costs of white papers and/or complete proposals in response to this BAA are not considered an allowable direct charge to any award resulting from this BAA or any other award. It may be an allowable expense to the normal bid and proposal indirect costs specified in FAR 31.205-18.

In accordance with federal statutes, regulations, and Department of Defense and Army policies, no person on grounds of race, color, age, sex, national origin, or disability shall be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving financial assistance from the Army.

Offerors submitting proposals are cautioned that only a Contracting or Grants Officer may obligate the Government to any agreement involving expenditure of Government funds. This BAA also applies to research proposals submitted to the RDECOM International Technology Centers.

For ARL Directorate Research Areas II.A.1, offerors should discuss the preferred performance period with the Technical Point of Contact (TPOC). For ARO's Research Areas II.A.2, it is preferred that proposals are submitted to cover a 3-year period and include a brief summary of work contemplated for each 12-month period so that awards may be negotiated for an entire 3-year program or for individual 1-year increments of the total program.

All administrative inquires regarding this BAA shall be addressed to voice mailbox number 919-549-4375. Technical questions should be referred to the TPOCs shown following each research area of interest. When an inquiry is made, please clearly state your name, correct spelling, and telephone number.

This BAA is available on the following websites:

http://www.arl.army.mil/www/default.cfm?page=8

http://www.grants.gov

www.fbo.gov

This BAA is a continuously open announcement valid throughout the period from the date of issuance through 31 March 2017, unless announced otherwise, and supersedes the ARL BAA dated October 2007. Amendments to this BAA will be posted to the FedBizOpps web site and published at the above websites when they occur. Interested parties are encouraged to periodically check these websites for updates and amendments.

JOHN M. MILLER
Director
Army Research Laboratory

A. **Required Overview Content**

1. Agency Name:
U.S. Army Research Laboratory

Issuing Acquisition Office:
U.S. Army Contracting Command-Aberdeen Proving Ground, Research Triangle Park Division

2. Research Opportunity Title:
ARL/ARO Core Broad Agency Announcement for Basic and Applied Scientific Research for 15 May 2012 – 31 March 2017

3. Announcement Type
Initial Announcement

4. Research Opportunity Number:
W911NF-12-R-0011

5. Catalog of Federal Domestic Assistance (CFDA) Number and Title:
12.431 – Basic Scientific Research

6. Response Dates:
This BAA is a continuously open announcement valid throughout the period from the date of issuance through 31 March 2017, unless announced otherwise, and supersedes BAA W911NF-07-R-0001 (including all modifications) dated October 2006. Amendments to this BAA will be posted to the FedBizOpps web site and published at the above-mentioned websites when they occur. Interested parties are encouraged to periodically check these websites for updates and amendments.

II. DETAILED INFORMATION ABOUT THE FUNDING OPPORTUNITY

A. Funding Opportunity Description

The funding opportunity is divided into three sections: 1) Army Research Laboratory Core Competencies; 2) Army Research Office Division Research Areas; and 3) Other Programs.

1. ARMY RESEARCH LABORATORY CORE COMPETENCIES

a. CORE COMPETENCY 1: MATERIALS SCIENCES

1.1 Structural Materials and Components

1.1.1. Composite Materials. Proposals are requested involving fundamental and applied research of advanced materials in relation to polymer-, metal-, and ceramic-matrix composites and their hybrids, and extending theory and experimental methodology where current theory and techniques are not adequate for modeling, analyzing, or characterizing the synthesis, processing, microstructure, and properties of these materials and material systems. The broad areas of interest include dissimilar material bonding, adhesion, interpenetrating networks, thermosetting-thermoplastic adherent interfaces, multilayer composites, and hybrid fiber systems; synthesis and thermo chemical and mechanical analysis of constituent material forms; surface analysis techniques; energetic and chemical interphase/interface development/properties; cure behavior and modeling; transport and degradation properties including thermal, oxidation, electrical, and chemical; effects of additives and fiber treatments on formation and properties of the fiber-matrix and hybrid system interphase/interface; failure modeling and analysis; special thermoplastic composite issues including intimate and healing mechanisms and modeling; interactions of composite and hybrid systems with electromagnetic and radioactive fields; modeling/analysis of void formation and effects of voids and other defects on strength, modulus, microcracking, etc.; composite-specific testing and analysis technique development and utilization including mechanical and electromagnetic property tests, fiber and matrix property tests, environmental exposure tests, etc.; statistical analysis of composite properties; assessment and analysis of industry-reported composite material property data; fundamental concerns and mechanisms for novel curing including electron beam, dielectric, microwave, etc.; physical property analysis; hygrothermal effects testing and analysis; thermal and oxidative stability; impact and delamination resistance; viscoelastic effects; analysis of process-induced properties; micro- and macromechanical analysis of fracture, buckling, delamination, etc.; mechanics of laminated forms; numerical analysis; material durability and performance; and fundamental research in new material developments including fiber forms and surface modifications, low-density core materials, low-viscosity thermosetting resins, and processable phenolic resins, etc. Special emphasis should be placed on composite materials supporting personnel and vehicular armor; on low-observable and ultra-lightweight, multi-functional materials for aircraft, flight body, ground vehicle, and on soldier systems; on materials for munitions, ordnance, cannons, armaments, and their sub-components, and on the characterization of polymer/hybrid materials surfaces and interphase phenomena, adhesive bonding, durability/life extension, and smart/intelligent material systems. Reporting of scientific results and conclusions will be

incorporated into scientific meetings and publications including general literature (conference proceedings, journals, etc.), technical reports, and standardization documents.

Technical Point of Contact: Dr. James Sands, e-mail: james.m.sands.civ@mail.mil, (410) 306-0878

1.1.2. Advanced Materials and Materials Processing. ARL is seeking proposals for high quality research and development in advance materials and materials processing approaches that are critical to Army applications. The Army requirements are driven by the need for lighter weight, lower cost, environmentally friendly, and enhanced durability. Reduced weight / ultra-lightweight is the goal for all weapon systems and logistics support items including ground and air vehicles, missiles, munitions, etc. Major future weapon systems include the Future Force and the Ground Soldier System. There is an interest in materials and manufacturing processes that will reduce the cost of weapon systems, and increase capability without additional cost. Army weapon systems are being extended beyond original design lifecycle. Accordingly, there is an interest for materials and processes that will help lower the operating and support costs of weapon systems. Environmentally friendly materials and processes will impact disposal and cleanup costs. Processing technologies of interest include those that will be applicable during high rate production and also for rapid prototyping. The objective of rapid prototyping is to reduce lead-time and, where possible, to make cost independent of order size. Proposals may impact materials currently in use within existing systems or look forward to future systems, subsystems, or support items. A few areas of interest includes: (i) materials such as bulk and composite amorphous materials, nanomaterials, advanced metal matrix composites, polymer materials, etc. Some goals are to discover, synthesize and process bulk and amorphous metallic alloys for potential applications such as kinetic energy applications; novel processing for refractory metal and alloy warhead liners for shaped charge and explosively formed projectile applications; other example uses include structural, armor, coatings, multifunctional, etc. applications, (ii) processing methods include joining, bonding, laser processing, shaping, etc. Objectives include: weld characterization, successful joining of difficult to weld materials, dissimilar metals; rapid prototyping, direct metal deposition techniques, processing to enhance surface properties, etc.

Technical Point of Contact: Dr. James Sands, e-mail: james.m.sands.civ@mail.mil, (410) 306-0878

1.1.3. High Rate Deformation and Failure of Materials. Proposals are requested to investigate the high rate behavior of materials undergoing deformation beyond the elastic limit to include fracture and failure. Materials of interest include polymers, high-density metals, ceramics, materials used for constructing urban structures, and materials capable of energetic response to mechanical stimuli. The broad area of interest covers experimental, computational, and theoretical investigations with an emphasis towards the development of a computational predictive capability of high rate deformation and failure of materials subjected to ballistic impact conditions. Advanced constitutive characterization and modeling, equation of state, dynamic fracture (both experimental and computational), material decohesion, and thermomechanical coupling are included in this wide area of interest. Also included are experimental and computational issues associated with the bridging of length scales ranging from

microstructural to macroscopic. Reporting of scientific results and conclusions may be incorporated into scientific meetings and publications including general literature (conference proceedings, journals, etc.), technical reports, and standardization documents.

Technical Point of Contact: Dr. Todd W. Bjerke, e-mail: todd.w.bjerke2.civ@mail.mil, (410) 278-5819

1.1.4. Structural Mechanics. Research proposals are requested for physics-based first principle analytical models and other advanced computational, analytical and experimental methodologies that will advance the development of extremely lightweight, adaptive, durable, and damage tolerant structures.

Technical Point of Contact: Dr. Anindya Ghoshal, email: anindya.ghoshal.civ@mail.mil, 410-278-7358.

1.1.5. Multifunctional Structures. Capabilities for revolutionary multifunctional structures embedded with combinations of power, electrical, actuation, or biological properties to increase system-level capability, performance, efficiency and mobility.

Technical Point of Contact: Dr. Mark Bundy, email: mark.l.bundy2.civ@mail.mil, 410-278-4318.

1.1.6. Adaptive Structures. Innovative adaptive structures integrated with smart materials having shape memory characteristic for morphing, healing capability for self-repair, or nanoconductive sensing ability for structural health monitoring.

Technical Point of Contact: Dr. Mark Bundy, email: mark.l.bundy2.civ@mail.mil, 410-278-4318.

1.1.7 Nanomaterials Processing. The ARL is seeking proposals for high quality research and development in furthering the science and application of nanotechnology to enhance weapon systems and warfighter capabilities. Encompassing nanoscale science and technology includes imaging, measuring, modeling, manipulation and control of nanostructural matter from the atomic level to the macroscopic, including the nano, micro and mesoscales. The challenges that impede the rapid transition of nanotechnology to applications and fielding are materials and manufacturing processes. There is a lack of transformational technologies for manufacturing nanostructures and nanomaterials in large quantity and low cost. Whether the product is nano-structured materials for armor or nano-particles for protective coatings, the pervasive technical challenge in processing and manufacturing of nano-materials is the ability to control their disbursement, distribution, stability, morphology and microstructural design throughout the synthesis and consolidation phases. There is a need to resolve the fundamental barriers to achieving the unique properties and capabilities available from nanotechnology. Significant challenges are nucleation, phase transformation, equilibrium and non-equilibrium crystal structures, thermodynamics, diffusion, kinetics, oxidation and grain growth and particle agglomeration that arise from processing and manufacturing techniques. There is a need to enhance the development and understanding of the synthesis, characterization and design of

nanoscale materials with superior mechanical, functional and environmental behavior based upon predictive modeling of their properties.

Research to develop tools and methodologies to create and retain unique nano-derived properties from nano-synthesis through component processing will allow for the insertion of higher strength, higher toughness, with high-temperature stability of nanostructured metals and alloys for structural and other niche applications. Of interest are the development of processing science, novel fabrication techniques, or scale up for the fabrication of powdered precursors and bulk products, including near-net formed from them. Specific materials include organic and inorganic materials, refractory metals and alloys, ultra lightweight metals and alloys, as well as more conventional alloy systems. Additional focus areas relate to the use of integrated computational methods designed and implemented to reduce the development and insertion timeline from conception to production and include the growth and characterization of embedded nano-sized constituents designed for material and multi-functional performance, including health monitoring (i.e. fatigue, corrosion); and investigations of novel methods leading to large-scale, large-quantity processing of nano-materials. The goal of this research is the rational design of safe, yet high performance nanoscale materials, efficient and inexpensive manufacture of these materials and the incorporation of the nanoscale materials into microscale or larger components. The submission of proposals that combine or integrate these phenomena is encouraged.

Technical Point of Contact: Victor K. Champagne, email: victor.k.champagne.civ@mail.mil, (410) 306-0822

1.2 Electronic Materials and Devices

1.2.1. MicroElectroMechanical Systems (MEMS). ARL is interested in receiving proposals on novel materials, devices, and integration approaches for MEMS sensors and actuators. ARL is also interested in integration approaches for nanoenergetic materials on a chip, as well as MEMS devices and structures that either benefit from the presence of an energetic material or enable initiation, characterization, or control of the energetic reaction. Technical areas of interest include, but are not limited to, the following:

a. Low or no power MEMS sensors and actuators
b. Shock, acceleration and angular rate sensors and switches
c. Bio-inspired and bio-mimetic sensors and actuators
d. Size, weight and power constrained solutions for soldier born sensors and micro autonomous systems
e. MEMS grippers and reversible adhesives
f. Mechanical or electromechanical switches that sense and change state upon change in an environmental condition, such as temperature, acceleration, pressure, etc.
g. Materials and methods for integration of energetic materials on chip
h. Methods and devices for conversion of energy from energetic reactions to other useful forms on chip (heat, light, pressure, electrical current, etc)
i. Novel microactuators based on energetic chemical reactions

Technical Points of Contact: Dr. Luke Currano, luke.j.currano.civ@mail.mil, (301) 394-0566.

1.2.2. Nanoelectronics and Nanosensors for Army Applications. ARL is interested in receiving proposals addressing the technical barriers and advancing the state of the art for nanoelectronic devices. Technical areas of interest include, but are not limited to, the following:

a. Theoretical and experimental studies of nanodevices
b. Novel concepts for multifunctional electronics and sensors, including design, fabrication and testing approaches
c. Graphene, BN, Diamond Like Carbon, MoS2 and Nano carbon and other ambipolar class of electronics, devices and circuit and components
d. Graphene/CNT micro-supercapcitors and hybrid system integration and packaging
e. Novel 2-D and 3-D materials for full spectrum IR Imaging and Thermal Photo Voltaic (TPV) devices
f. Plasmonics and Nano-Photonic devices, integration, testing, and circuit design
g. Transparent, printable and stretchable electronics
h. Ultra compact low power and high frequency RF communications
i. High frequency RF devices
j. Beyond CMOS electronics
k. Integration with MEMS, NEMS, nanoenergetics, and other technologies

Technical Point of Contact: Dr. Madan Dubey, madan.dubey.civ@mail.mil, (301) 394-1186.

1.2.3. Piezoelectric MicroElectroMechanical Systems (PiezoMEMS) Technology. ARL is interested in receiving novel proposals that address the technical barriers associated with improving the current state of the art in piezoelectric thin film materials, devices, and components used as sensors, actuators, and micro-mechanical structures. Technical areas of interest include, but are not limited to, the following:

a. Theoretical and experimental studies of electro-mechanical interactions in solids.
b. Studies of micro-mechanics that impact materials and device reliability, reproducibility, and device design.
c. Investigation of piezoelectric thin films including texture, ferroelectric, dielectric, piezoelectric, and elastic properties under a variety of conditions including electric field, temperature, stress, and strain.
d. Fabrication technologies to improve materials reliability and reproducibility, to enable 3-dimensional processing of actuators and sensors, and to achieve extremely large piezoelectric coefficients.
e. RF MEMS technology including switches, phase shifters, resonator and filters, transformers, tunable microwave components, and integrated package and assembly strategies.
f. mm-Scale Robotics including actuator and proprioceptive sensor design and modeling, fabrication and integration strategies for achieving high force, large displacement actuation, and design and integration strategies for power, power management, control, and communication systems.

Technical Point of Contact: Dr. Ronald Polcawich, ronald.g.polcawich.civ@mail.mil, (301) 394-1275.

1.2.4. Emerging Technologies for Semiconductors. Innovative research is sought in the areas of modeling, processing and fabrication of advanced electronic materials & devices for integrated systems that are critical to Army applications. The major focus in this request includes flexible electronics, multi-scale modeling, and novel characterization technologies that can be used to aid the understanding, development and fabrication of advanced materials and technologies for next generation microelectronics. Fabrication and processing of semiconductors, interconnects, device structures, 3D and heterogeneous integration, and the characterization and control of trace impurities, defects and interfaces in semiconductors and masks are of interest, particularly for sub90-nm devices and circuits. Principal emphasis is on surface or interface control during processing of these materials, characterization of their near-surface transport behavior and surface properties, and modeling or theoretical predictions of their properties.

Technical Point of Contact: Dr. Glen Birdwell, Anthony.g.birdwell.civ@mail.mil, (301) 394-0601.

1.2.5. Small RF (micro-sensor) Systems. The Army is interested in lightweight, affordable radar systems that are suitable for and have the ability to sense, locate, and identify targets from any of a variety of surveillance sensor platforms such as robots, UAVs or future micro-sensor platforms. The development of such a system may include phenomenology (signature) measurements in an effort to optimize the hardware and software. The systems or techniques proposed must have the high speed necessary to perform in real time, coupling with peripheral processors.

Technical Points of Contact: Mr. Edward Viveiros, Edward.a.viveiros2.civ@mail.mil, (301) 394-0930 or Mr. Eric Adler, eric.d.adler.civ@mail.mil, (301) 394-0933.

1.2.6. Microwave Device and Analog Signal Processing Research and Development. The Army requires improved microwave devices that are reliable and cost effective, as well as lightweight, reliable signal processing components to handle large volumes of data on a real-time basis. Desired are novel proposals that address the technical barriers associated with improving the state of the art of such devices and components. Technical areas of interest include, but are not limited to, the following:

a. Physics-based modeling of microwave devices, components, packages, and radiating structures using semiconductor analysis and computational electromagnetics.
b. The research and/or novel application of low-cost analog signal processing components based on acoustic wave technology, acoustic charge transport, magnetostatic waves, or high-temperature superconducting materials, either singly or in combination.
c. Emphasis should be directed toward achieving larger bandwidth, reducing insertion loss and power consumption, or lowering fabrication costs.
d. Novel linearization techniques.

Technical Points of Contact: Dr. Joe Qiu, joe.x.qiu.civ@mail.mil, (301) 394-2532 or Dr. Frank Crowne, frank.j.crowne2.civ@mail.mil, (301) 394-5759.

1.2.7. Broadband Analog, Microwave, Millimeter-wave and Mixed-signal Integrated Circuits and Processing Architectures. The Army requires the generation and analysis of broadband complex-modulated vector-waveforms for applications in communication, radar and electronics warfare. The Army is also looking for innovative digital signal processing circuits and architectures to process the large amount of data associated with the increased bandwidth. Technical areas of interest include but are not limited to the following:

a. High-speed low-power digital-to-analog converters (DACs) and analog-to-digital converters (ADCs).
b. Circuits and techniques to generate and distribute highly stable and low jitter clock signals for DACs and ADCs. Techniques to synchronize converter clocks with front-end local oscillators.
c. Novel broadband high-frequency circuits and techniques for modulation and demodulation of complex waveforms.
d. High capacity and parallel digital signal processing techniques. These may include both ASIC and FPGA approaches.

Technical Points of Contact: Mr. John Penn, (301) 394 0423, john.e.penn16.civ@mail.mil or Dr. James Wilson, james.e.wilson889.civ@mail.mil, (301) 394-0328.

1.2.8. Frequency Control. The Army requires study and research of frequency control device technology since the accuracy and stability of RF sources and clocks are key determinants of the performance of radar, C3I, navigation surveillance, EW, missile guidance, IFF systems and sensors.

a. High purity quartz and new piezoelectric materials.
b. Gun Hardened RF oscillators and clocks for smart munitions.
c. Low-noise vibration resistant RF sources and clocks for radar, communications, navigation surveillance, EW, missile guidance, IFF and sensors.
d. Low-jitter clocks and low phase noise RF sources from HF (1 MHz) to W-band (100GHz).
e. Resonator theory, modeling and computer aided design of resonators and oscillators including 3-d finite element models of resonators with improved algorithms to reduce super computer calculation times.
f. Processing and packaging of high stability resonators and RF sources, including mode suppressant techniques to limit degradation of filters and RF sources, mounted in below cut-off wavelength size modules.
g. Resonators and oscillator theory leading to optimum performance.
h. Ultra-low-noise measurement techniques of SAW and bulk resonators, piezoelectric material parameters calculation, modeling and measurement, diagnostic analysis and probing techniques, including fundamental noise studies involving 1/f noise.
i. Thin film piezoelectric resonators and micro-resonators (MMIC compatible) for resonators filters and RF sources.
j. Hardware and software development of low power, high-stability clocks.
k. Design of miniature low loss (<2dB) piezoelectric resonators for compact size, narrow bandwidth bandpass filters (.01%-5%).

Technical Points of Contact: Dr. Joe Qiu, joe.x.qiu.civ@mail.mil (301) 394-2532 or Dr. Frank Crowne, frank.j.crowne2.civ@mail.mil, (301) 394-5759.

1.2.9 High Power RF Sources and Amplifiers. The Army requires study and research in the areas of the following high-power RF technologies for communications, radar systems, electronic warfare (EW), and countermeasures. Solid-state III-V materials and devices, free-space and circuit based power combiners, microwave power modules, vacuum electronic devices. Solutions are sought for the above sources with regard to the following characteristics: compact size and low weight, improved high reliability, low cost, increased life, reproducibility, reparability and simplicity of fabrication, long shelf life, broad bandwidth (or tunability), high power, high efficiency, high gain, high voltage stand-off capability and low noise. Proposed designs must show the potential for meeting one or more of the above requirements. Solutions are also sought for test and evaluation techniques for the characteristics listed. Innovative simulation/computer techniques for the proposed design approaches are encouraged.

Technical Point of Contact: Dr. Tony Ivanov, tony.g.ivanov.civ@mail.mil, (301) 394-3568.

1.2.10 RF-to-THz Devices and Integrated Circuit Technology. The ARL is interested in research on innovative electronic substrate and epi-materials, devices, monolithic circuits, and integration techniques for digital, mixed mixed-signal, and RF- to-sub-millimeterwave-to-TeraHertz applications. Work should involve devices and ICs integrated circuits, and subsystems built upon new Si-based, III–V, III-nitride, and II-VI materials, novel device structures, innovative circuit topology, nano technology, and multi-level, and/or heterogeous integration technology.

Technical Points of Contact: Dr. H, Alfred Hung, hingloi.a.hung.civ@mail.mil, (301) 394-2997 or Mr. John Penn, john.e.penn16.civ@mail.mil, (301) 394-0423.

1.2.11 RF Wide Band Gap Semiconductors, Devices, and Circuits. The Army requires advanced wide bandgap RF semiconductor devices such as HEMTs, varactors, and Gunn diodes for high-frequency and/or high-power applications in the GHz regime and beyond. Materials of interest include group III-nitride semiconductors, SiC, diamond, ZnO, or other materials. Researchers should propose novel device structures, material growth, fabrication and characterization techniques as well as device modeling concepts for advancing the state of the art. Areas of interest include:

a. New structures such as III-nitride based devices containing tertiary and quarternary compounds to take advantage of polarization and band gap engineering concepts. Also of interest are other lower dimensional devices structures such as nanowires and constrained structures entailing multi-scale modeling.
b. Advanced material growth techniques that reduce defects to improve device efficiency and modulation / switching performance.
c. Characterization techniques to qualify and quantify traps and other defects, carrier transport characteristics, hot spots, strain, surface charge, material composition, etc.
d. Computational electronics techniques including technology computer aided design, Monte Carlo carrier transport simulation, or density functional theory techniques to accurately describe material characteristics and device performance and explain measured results.

e. New methods to assess device reliability and determine cause of lifetime reduction.
f. Model extraction techniques to obtain lumped element models for circuit designs up to the GHz to THz frequency range.
g. Devices support RF/power applications for Army systems operating in extreme environments such that high temperature performance and thermal management and packaging issues become critical.

Technical Points of Contact: Dr. Pankaj Shah, pankaj.b.shah.civ@mail.mil, (301) 394-2809 or Mr. Edward Viveiros, edward.a.viveiros2.civ@mail.mil, (301) 394-0930.

1.2.12. Antenna Front End and Receiver Technology for Multi-Function Radio Frequency Architectures The Army has an interest in researching affordable shared aperture, single system architectures which could implement radar, radiometric, combat ID, command and control, target acquisition, communications, signals intelligence (SIGINT), satellite on the move (SOTM), and communications on the move (COTM) functions – depending on platform requirements. Supporting technologies include, but are not limited to, electronically scanned antennas, multi-beam antennas, multi-band/broadband antennas, and wafer level antennas. Specific areas of interest are broadband antenna elements, low loss phase shifters, low loss delay lines, true time delay architectures, low loss splitters and combiners, planar technologies, issues associated with polarization switching, instantaneous bandwidth, low-loss high performance switches, simultaneous multiple beam formation, wide-bandwidth RF components and modules (LNA's, PA's, Mixers), and high performance design tools. Other supporting technology includes digital receiver technology, high performance A/D converters, high performance filters, programmable synthesizers and signal processing architectures.

Technical Points of Contact: Dr. Steven Weiss, steven.j.weiss14.civ@mail.mil, (301) 394-1987 or Mr. Eric Adler, eric.d.adler.civ@mail.mil, (301) 394-0933.

1.2.13. Conformal Antennas. The Army has an interest in integrated antennas and antenna arrays that are platform conformal. Such platforms are broadly defined and can be as diverse as the side of a vehicle, the wing of a UAV or the backpack of a soldier. The antennas should exploit novel techniques (e.g., metamaterials, artificial ground planes, electrically small antennas on a chip, etc.) to achieve comparable performance with traditional antenna architectures such as whip, dish, and slots. An important metric is comparable performance to legacy antennas while reducing cost and increasing affordability.

Technical Point of Contact: Dr. Steven Weiss, steven.j.weiss14.civ@mail.mil, (301) 394-1987.

1.2.14. Vehicle Integrated Antenna Technologies. ARL is soliciting innovative research proposals in the area of vehicle integrated antenna technologies. The proposed research should investigate novel approaches that enable advances of in-situ antenna designs for application to covert RF systems on military vehicles. Such advances are required to allow transmitting and receiving antennas on vehicle platforms to be concealed or completely covert. All technologies ranging from camouflaged to embedded antennas are solicited. Both high and medium gain wideband antennas are required with polarization diversity from circular to dual polarization being highly desirable. Primary design considerations shall be to reduce the visual signature of

ultra wideband antennas that exhibit similar EM performance to current state of the art solutions. Antenna concepts for three frequency bands of interest are sought: 100MHz to 1 GHz, 1 GHz to 3 GHz, and greater than 3 GHz with emphasis on circular polarization approaches. Overlapping frequency bands are also of interest. Proposals ranging from multiple covert antennas to multifunction RF systems with simultaneous transmit and receive functions are solicited for application to complex detection and geolocation systems.

a. Applications of such integrated antennas for covert operations fall into two general classes: 1) sensitive receiver systems and 2) high power radar transmitters. The host platform for these antennas can be a full size tactical vehicles requiring broad beamwidth (>40°) or omni-directional or small robotic vehicles (Talon or unmanned aerial vehicle requiring directional antennas with reduced size.
b. The Vehicle Integrated Antenna Technologies program will establish the feasibility and demonstrate new and innovative antenna designs that have the potential to enhance the way that the Department of Defense (DoD) installs antennas on vehicle platforms. The scope of this BAA is limited to demonstrating the innovative designs proposed, providing sufficient antenna details to allow antenna simulation verification, and describing the opportunity that exploitation of the approach could provide the DoD. Antenna performance must be compared to commercially available equivalents to demonstrate advantages of the proposed design. The as-installed antenna on the host vehicle must have similar performance while providing reduced visual signature compared to COTS alternatives. Efforts that successfully demonstrate feasibility of the antenna design may lead to future, longer term efforts that fully investigate and develop the technology necessary to exploit integrated antennas for ground vehicle applications.
c. Examples of research topics that are of interest include, but are not limited to, the following:
    1) Use of Artificial Magnetic Conductors to Reduce Ground Plane Effects for Wideband Antennas – provide usable bandwidth over an octave or more for antennas fully integrated into ground vehicles.
    2) Platform RF Systems – Innovative antenna concepts that replace vehicle structural elements such as a bumper that serves as an antenna. Novel applications of camouflaged antennas such as antenna elements embedded in glass or composite structures will also be considered. Antenna systems that can be integrated into the platform structure during the manufacturing process are of interest.
    3) Platform Feed Systems – Innovative feed systems that improve performance (multi-function / reduced co-site / improved gain and pattern) and reduce the impact on platform integration. Feed systems that allow a single RF cable to feed multiple antennas and feed systems that can be integrated into the platform structure during the manufacturing process are of interest.
    4) Integrated Platform-Enhanced Aperture Design – Aperture design research to improve performance by incorporating the platform as part of the aperture design to obtain omni-directional pattern coverage.
    5) Metamaterial Aperture Design - Volumetric characterization of antennas with metamaterial apertures integrated into the vehicle structure is of interest. In addition, further research into the application of metamaterials in antenna design, to include embedding them in armor, is also of interest.

6) Leaky Wave Antennas - Research into Leaky Wave antennas that can be fully integrated into the vehicle structure and scanned electronically are of interest. The approaches should consider the ability for vehicles to radiate in all directions and at different frequencies (VHF is of interest).
7) Wideband, Multi or single element, Multi-function Platform Antenna/RF Distribution Systems: Development of RF distribution and antenna technologies that reduce visibility are of interest.

d. Proposals that describe integrated antenna technologies that could substantially reduce the visual impact of RF systems on ground vehicles but do not directly fit into one of the topics listed above can be submitted under this BAA.

Technical Point of Contact: Dr. Steven Weiss: steven.j.weiss14.civ@mail.mil, (301) 394-1987.

1.2.15. Millimeter-wave and Terahertz Imaging. The Army has an interest in active and passive sensors for imaging during conditions of fog, dust, smoke, and clouds. The millimeter-wave/terahertz regime offers this capability with a form factor that is smaller than microwave systems. The technology can be applied to the detection of military vehicles, air- and ground-vehicle obstacle avoidance, aircraft navigation and landing in degraded visual environments, targeting and communications. Specific research areas of interest include millimeter-wave and terahertz phenomenology, polarimetry, synthetic aperture imaging, enabling device technologies, calibration techniques, quasi-optical design, electronic scanning, motion compensation for sparse arrays, signal processing such as compressive sensing and computational imaging, and target/clutter models. Millimeter-wave/terahertz solutions for concealed weapons detection are also of interest.

Technical Point of Contact: Mr. David Wikner, david.a.wikner.civ@mail.mil, (301) 394-0865.

1.2.16. Next Generation Digital Imaging. ARL is actively engaged in research leading to next generation digital imaging systems. Although several critical technologies, including image collection optics, solid state detectors, digital post-detection processing, and image display, impact critically the performance of digital imaging systems, traditional approaches to specifying these components for such systems do not pay sufficient attention to the interplay between them and the subsequent impact that has on overall system performance. In contrast, our integrated approach optimizes the design of the component technologies in parallel. Such an approach provides improved performance while also addressing size, weight, cost and power issues. Recent developments in detector technology, computational capabilities, and the manufacture of optical surfaces facilitate an integrated imaging design approach. We are interested in proposals that address two or more of the following topics: image reconstruction, aspheric optical design, information theoretic imaging metrics and numerical optimization techniques. Topics may be submitted on imaging systems for the visible, infrared, millimeter wave, and terahertz regimes.

Technical Point of Contact: Dr. Joseph Mait, joseph.n.mait2.civ@mail.mil, (301) 394-2462.

1.2.17. Directed Energy. ARL is the designated leader for the Army's directed-energy weapon (DEW) technology base program. This includes high-power microwave (HPM), non-nuclear electromagnetic pulse (EMP) (NNEMP), e-beam/x-ray, and high-power acoustics and air

pressure waves. ARL has a continuing interest in a broad spectrum of research in these areas, including, but are not limited to:

a. A better understanding of the susceptibility of developmental and fielded systems to attack by an RF DEW threat.
b. Improved methods and technologies for hardening systems against that threat.
c. The development of new components (sources, pulsers, and antennas) for possible future application in an RF weapon system:

(1) Generation of microwave power/energy--Novel pulsers/sources are needed that have programmable pulse characteristics so that rise time, pulse width, repetition rate and frequency bandwidth can be changed electronically, along with frequency-sweeping capability over octave bandwidths. Design considerations of low-cost compactness and high efficiency are of particular interest. Switch technologies that convert dc to RF directly with picosecond rise time capability are of interest. Radio frequency oscillators/amplifiers that use picosecond electronics to obtain programmable RF outputs are desired, along with picosecond RF exiters to drive amplifiers. Portable kilowatt and megawatt RF/microwave amplifiers with octave bandwidths are sought. Frequencies of interest are from 0.3 to greater than 10 GHz, with microsecond pulse durations and high duty cycles. Efficiencies should exceed 30 percent and gain should exceed 30 dB. Novel technologies suitable to extend high-power pulse amplifiers to 40 GHz or higher are also sought. Bandwidths should be multi-gigahertz and gains should exceed 20 dB. Emphasis will be placed on efficiency, compactness, and portability. Source technology that is based on solid-state transmitters using phased array antennas is of increasing interest.

(2) The effects of RF and microwave power/energy--Material susceptibility is the primary area of concern. Included are composite materials, electro-optical systems, computers, communications, displays, receivers, sensors, monolithic microwave integrated circuits (MMIC), very high speed integrated circuits, and other sophisticated electronic systems, subsystems, and devices. Upset and damage to electronic devices and their failure mechanisms, caused by RF transients, are of interest. RF coupling and failure mechanisms that are affected by such parameters as frequency, pulse width and shape, repetition rate, amplitude, and polarization are also of interest. Novel schemes are solicited for techniques that can be used for protection against the RF and HPM threats. Advanced methods and techniques are needed for housing composite materials. Methods for the theoretical understanding and prediction of RF effects from transients with a wide range of pulse characteristics are of great interest.

(3) Hardening to RF energy--Army system survivability is enhanced using hardening techniques that are readily verifiable, reliable, and maintainable in the RF environment. ARL needs improved interactive models that yield statistical parameters of the source/system environment for complex scenarios. Models are sought that are suitable for understanding the mechanisms of device susceptibility and leading to improved devices. Detailed models have been developed that use excessive computer resources. New approximate techniques need to be developed to readily accommodate complex scenarios. Models are needed for composite materials, including both resistive and inductive effects. Innovative techniques for hardening front- and back-door entry ports of systems are sought. Hardening includes techniques to limit the throughput of the path or to raise the susceptibility threshold of devices subject to burnout or upset from RF energy. Hardening devices are of interest that:

a. Can handle large average and peak powers.
b. Can limit or switch unwanted HPMs in protecting the system or subsystem.
c. Have frequency and amplitude selectivity. Vacuum microelectronics, semiconductor, and magnetic technologies are all of interest.

(4) RF microwave diagnostics--Novel, non-perturbing RF/microwave diagnostics are sought. Such devices should be able to measure RF/microwave power for microsecond durations and have rise times in the 0.1- to 10-ns range. The diagnostics should be mountable inside enclosures near complex structures. High-frequency probes that can operate above 2 GHz are also of interest. Quality measuring techniques are needed for seams, joints, and contracts for composite materials. The Army has a great interest in testing military systems in a microwave environment. Research topics related to the Army's system testing effort include instrumentation and measurements, anechoic chamber design and characterization, microwave source development, novel testing techniques to allow a military system to be quickly evaluated in a microwave environment, experimentation to determine microwave effects, modulations of microwave signals, and high-power sources.

(5) Battlefield effectiveness of RF-DEW--The Army, as well as DoD in general, is involved in the impact of RF effects on the battlefield. Novel approaches are sought to develop techniques/models that can describe the effects of system degradation on battlefield systems and how the systems may impact the outcome of the battlefield-appropriate measures of effectiveness must be defined for various types of weapons and sensors that could be affected by RF energy.

Technical Points of Contact: Mr. Eric Adler, eric.d.adler.civ@mail.mil, (301) 394-0933 or Mr. Mark Berry, mark.d.berry.civ@mail.mil, (301) 394-1228.

1.2.18. Prognostics & Diagnostics. The Army has an interest in the area of Prognostics and Diagnostics (P&D) health monitoring systems as applied to current/future weapons platform and the Soldier. The paradigm of time-based maintenance currently employed across the massive platform inventory is too costly and drains resources. A cost savings can be obtained in shifting the paradigm from time-based to condition-based maintenance. In term of physical platforms and hardware, embedded monitoring units will provide increased readiness and enhanced awareness of materiel condition. The soldier is recognized as the Army's most important asset. Being able to monitor and diagnose the Soldier's current condition is extremely valuable. Using environmental along with specific application sensors, signal processing will be necessary to predict the remaining operational life expectancy and the operational status of this range of diverse platforms. Understanding of the Physics of Failure and reliability engineering are crucial in the development of predictive algorithms. Establishing the appropriate algorithms to specific applications will be necessary for realization of P&D. P&D covers multiple areas such as ground and aerial vehicles, mechanical and electro-mechanical devices, electronic components, electronic communication and control systems, and biomedical systems.
Areas of significant interest include, but are not limited to, the following:

a. Framework/methodology in the development of prognostics and diagnostic routines
b. Prognostics prediction algorithms and diagnostic routines

c. Data acquisition systems with small form factor and minimal power consumption that are wirelessly networked & interrogable and extensible to existing platform diagnostics and readily available sensors. Compatibility with an open common architecture such is preferred.
d. Techniques for Built-in Self-Test (BiST)
e. Efficient techniques/processing of sensor data to reduce data storage requirements and methods of sensor fusion
f. Novel design and integration of environmental and application specific sensors that provides smaller footprint, power and ease of integration for P&D applications

Technical Point of Contact: Mr. Kwok Tom, kwok.f.tom.civ@mail.mil, (301) 394 2612.

1.2.19. Prognostics and Diagnostics for Condition-Based Maintenance. Research proposals are invited to develop improved prognostics and diagnostics (P&D) methods based upon the basic sciences, e.g. physics, material science based methods, and damage/fault diagnosis. The areas of technical interest include, but are not limited to, damage precursors nucleation and propagation, prognostic methods for the prediction of remaining useful life of a component and/or system, advanced sensing and sensor arrays, advanced signal processing techniques, sensor optimization and placement, data fusion, component and/or system level reasoners and reasoning methods, advanced P&D hardware/software, and Structural Health Monitoring that can reduce the logistics footprint and life-cycle costs while increasing vehicle availability.

Technical Point of Contact: Dr. Anindya Ghoshal, email: anindya.ghoshal.civ@mail.mil , 410-278-7358.

1.2.20. Bio-/Neuro-inspired Sensing and Information Management The Army requires research investigations in the area of arrayed, bio-inspired and/or biocompatible microscale sensors, and bio-/neuro-inspired approaches for extremely low power information management and control. This research is anticipated to establish a revolutionary new pathway for optimizing the coordination of orthogonal fused-sensing with computation in extremely size-, weight-, and power-constrained, arrayed heterogeneous sensor systems. Envisioned future applications range from autonomous control of mm-scale robotic platforms, to helmet- or textile-integrated physical health monitoring or situational awareness flexible sensor network arrays. This research strives to determine a set of minimalist solutions for information management and decision making in constrained heterogeneous sensor systems. In particular, it seeks to 1) determine the lower limit of sensor resolution required to achieve a high probability decision, 2) rigorously incorporate error and probability into sensor processing and decisions, 3) exploit orthogonal data streams to reduce uncertainty and enhance decision/actuation fidelity, 4) optimize control logic to the specific temporal dynamics of a system, and 5) incorporate information management logic directly into novel sensor nodes and arrays. Key research areas include, but are not limited to, the following:

a. Investigation of bio/neuro-inspired control theory and multi-sensory perception algorithms for arrayed sensor information processing, actuation, and/or information management in relevant time scales. These algorithms may include multi-scale calculation approaches to modeling.

b. Design, simulation, fabrication, test, and evaluation of electronic, electromagnetic, and electromechanical microsensor devices required to effect required actuation, communications, navigation, or information processing on extremely size-, weight-, and power-constrained systems.
c. Design, simulation, fabrication, test, and evaluation of biocompatible microsensor devices for applications including helmet- or textile-integrated physical health monitoring or situational awareness flexible sensor network arrays.

Technical Point of Contact: Dr. William Nothwang, william.d.nothwang.civ@mail.mil, (301) 394-1163.

1.2.21. Development of Signature Management Materials and Devices*. There is an interest in proposals on signature management materials and devices. These devices and materials can have structural and/or non-structural properties, and shall exhibit unique emissive, absorptive, reflective, and/or transmissive characteristics (both wide and narrow band) as a function of wavelength. The problems of inexpensive application and durability in the Army/military environment are also of interest.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

1.2.22. Integration of Signature Management Technologies *. There is an interest in proposals that examine the effectiveness of incorporating signature management technology into current and planned Army systems. Interest is in air, missile, ground, and soldier systems.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

1.2.23. Signature Management Measurements *. Proposals are requested for engineering measurement techniques and systems that would be effective for the development and evaluation testing of signature-reduction technology. Measurements are needed in the visual, infrared, and RF portions of the EM spectrum, as detailed in techniques.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

1.2.24. Management of Acoustic Signatures*. Proposals are requested that examine acoustic damping, both carrier wave and modulations of generated acoustic spectra. Applications are for ground vehicles, engine generators, and aircraft.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

1.3 Photonic Materials and Devices

1.3.1. Photonic Devices and Modules. Research is encouraged pertaining to active and passive devices as well as fiber based technology for sensing, communication including microwave, data and telecommunication and optical signal processing, Active device research includes the development of bulk and integrated sources, modulators, detectors and waveguides, and the development of technologies for their integration into processor architectures. Laser-based Terahertz systems are also sought. Active interface devices include semiconductor light emitting diodes (LED), lasers, vertical cavity surface emitting laser (VCSEL), photo detectors, solar cells, modulators, amplifiers and waveguides, with operation in the UV to IR spectral region, as well as integrated drivers and receivers. Also of interests are novel RF-Photonic devices, components, modules, and subsystems. Integrated array research should include on-chip processing, layout, mounting, and device cooling for one- and two dimensional arrays as well as the driver and receiver circuitry. Parameters of interest include number of elements, readout speed, noise levels, and dynamic range.

Technical Point of Contact: Dr. Lawrence Stout, lawrence.m.stout.civ@mail.mil, (301)394-4616.

1.3.2. Novel Optical Processing Algorithms and Techniques. Proposals relating to ideas for new processing systems and configurations are welcome. Methods for modulating light beams with signals of appropriate nature are of interest here. Also of interest are methods for realizing certain processing algorithms (e.g., multi-spectral image processing) and methods for detection using elaborate photosensitive devices (e.g., charge-coupled devices and CMOS detectors). Also of interest are algorithms and architectures for high speed data and telecommunications and networking as well as new concept and architectures to generate, transmit and processing RF-microwave signals in optical domain to improve the current RF systems including antennas and Radars. Important factors are speed, reasonable laser power requirements, insensitivity to lens aberration, small size, noise and environmental immunity, and other aspects of high performance. Both pre- and post-processing electronics are among the system components subject to possible improvement, with interfaces and coprocessors.

Technical Point of Contact: Dr. Lawrence Stout, lawrence.m.stout.civ@mail.mil, (301)394-4616.

1.3.3. EO/IR Sensors. Research proposals are desired that will lead to the ability to sense, locate, identify, and engage targets at tactical ranges. These sensors must reliably discriminate between targets and clutter and detect targets in the presence of counter-measures. For example, it is desired to detect a camouflage-netted vehicle partially obscured by foliage. Electro-optical and infrared sensors, both passive and active, and covering the spectrum from the ultraviolet to the far infrared, are of interest. Small size and gun or missile launch survivability are required for some applications and low cost is always important. Another area of interest is surveillance (UAV) and fighting platform (rotary wing and ground vehicle) based systems. Critical components of sensors, such as high-power eye-safe laser sources for laser radar, are of interest. Methods for fusing the outputs of various sensors and signal propagation modeling are also of interest. Applications include surveillance and target acquisition, target engagement for smart munitions, and navigation and obstacle avoidance.

Technical Point of Contact: Mr. Barry Stann, barry.l.stann.civ@mail.mil, (301) 394-3141 or Dr. Keith Aliberti, keith.m.aliberti.civ@mail.mil, (301)394-2320.

1.3.4. Infrared Detectors & Power Sources. ARL's research and development goal is to advance the technology for producing technologies for smart, multi-spectral, active and passive, focal plane arrays (FPAs) in ultra-violet to sub-millimeter wave spectral regions, with particular emphasis on the infrared region. Effort is also made to develop new concepts for photovoltaic and thermoelectric for power generation. Examples of areas of interest include, but are not limited to, the following:

a. Materials research, thin film growth, nano/bio-materials and device processing for fabricating single and multi-spectral detectors/arrays for active and/or passive sensors covering the major infrared bands. New materials development for power sources etc. Improvement in photovoltaic devices using: (i) Broadband operation with strong harvesting and conversion of below-bandgap photons; (ii) Nano-patterned structures for advanced light trapping schemes via holographic lithography;(iii) Nano-enhanced absorbers in the IR range; (iv) Advanced windows based on novel transparent conductors; (v). Bandstructure nano-engineering for high conversion performance; (vi). Nano-engineered electron processes for suppression of thermalization and recombination losses; (vii). Advanced passivation schemes for reducing surface recombination.
b. Epitaxial growth processes of materials on compliant and non-compliant substrates (e.g. HgCdTe, GaAs, InGaAs, etc.) for detectors, solar cells, thermoelectric and other optoelectronic applications. Research spectrally flexible hybrid thermophotovoltaic conversion consisting of optimized emitters, optical filters, cavity geometry and low bandgap, conformable thermophotovoltaic cells. Significant improvements can be achieved by (i). Optimizing photon recycling schemes for enhanced absorption; (ii). Bandstructure engineering for high conversion performance; (iii). Utilizing conformable photovoltaic cells for improving thermal heat management; (iv). Advanced materials and techniques to control spectral emission and transmission including photonic crystals and metamaterials.
c. Novel Uncooled FPA technology.
d. Computer simulation and modeling of single and multi-color detectors and systems.
e. Biologically inspired techniques for IR detectors and power source devices.
f. Development of advanced readout circuits including neuromorphic and bio-inspired circuit designs.
g. Development of Novel III/V materials and devices.

Technical Point of Contact: Dr. Priyalal Wijewarnasuriya, priyalal.s.wijewarnasuriya.civ@mail.mil, (301)394-0963 or Dr. Parvez Uppal, Parvez.n.uppal.civ@mail.mil, (301)394-5757.

1.3.5. Novel and Highly Scalable Diode-Pumped Solid State Lasers

a. Novel Solid State Lasers and Laser Materials: The Army is interested in research on innovative gain media, for example laser-quality ceramics; broad-gain media for frequency agile lasers in UV, NIR and Mid-IR; efficient solid-state materials for

stimulated Brillouin scattering, e.g., low threshold, high reflectivity, low sound propagation speed; specialty fibers and fiber lasers suitable for high average powers and power scaling; and laser materials for diode-pumped eyesafe lasers.

b. Techniques for Power Scaling of Diode-Pumped Solid State Lasers: The Army also has interest in innovative highly efficient pump-coupling techniques; innovative pump diode and active medium cooling techniques; passive and active laser beam/aperture combining methods; laser wavelength shifting techniques for achieving high average powers with optimum eyesafety; active and passive wavefront distortion compensating/OPD reducing techniques.

Technical Points of Contact: Dr. Larry Merkle, larry.d.merkle.civ@mail.mil, (301) 394-0941 or Dr. Mark Dubinskiy, mark.dubinskiy.civ@mail.mil, (301) 394-1821.

1.3.6. Hyperspectral/Multispectral/Polarization Imaging. ARL is engaged in the research and development of high performance compact, field-portable hyperspectral and multispectral imaging systems from the vacuum ultraviolet (UV) to the long wave infrared (LWIR) using tunable filter technologies including acousto-optic tunable filter (AOTF), Fabry-Perot etalon, diffractive optics, Michelson interferometer, liquid crystal, and other promising approaches. There is considerable interest in designing miniature sensors using micro electromechanical systems (MEMS) approach. Development of high performance hyperspectral/multispectral/polarization imager technology is critical to the Army's needs in chemical and biological agent detection as well as for target detection including buried mine detection. The range of applications includes spectroscopic remote sensing of biological and chemical agents, detection of explosives, detection of chem/bio agents on surfaces, pollution monitoring, detection of plumes, condition-based management, and polarization imaging for detection of targets and backgrounds, etc. System designs for compact automated hyperspectral/polarization imagers from UV to long IR incorporating suitable detectors, optics, image collection and processing software incorporating automated target detection algorithms and on chip preprocessing capabilities including biological inspired algorithms, electronically tunable polarimetric elements, suitable high sensitivity focal plane arrays, compact cooling systems, and schemes to improve the noise equivalent spectral radiance (NESR) of such imagers are of critical interest. Research in automatic processing algorithms for spectroscopic and spectropolarimetric imaging data including data storage techniques and data compression is encouraged. Topics of interest include efficient spectral dispersing elements; design of AOTF cells and transducers including designs to facilitate operation over two or more octaves in frequency; MEMS-based tunable etalons including materials, processing, fabrication, and packaging; diffractive optic elements including cooled lenslet arrays; design and fabrication of electronically tunable compact polarizing elements; higher sensitivity focal plane arrays with high dynamic range, fast efficient readout circuits, etc.; and compact packaging of such imagers for field portability and UAV and UGV operations.

Technical Point of Contact: Dr. Neelam Gupta, neelam.gupta.civ@mail.mil, (301) 394-2451.

1.3.7. Luminescent Materials and Devices for Displays. The ARL requires research investigations into luminescent materials, devices, and components, and relevant basic physics studies that couple luminescence, electrical, optical and mechanical properties of these materials

and devices. Research and study are needed to ensure that the displays available for the current and new systems will provide improved performance that is required to carry out complex military missions. ARL is interested in receiving novel proposals that address the technical barriers associated with improving the current state of the art in luminescent materials, devices, and components used as the basis for the display technology in Army systems. Technical areas of interest include, but are not limited to, the following:

a. Theoretical and experimental studies of luminescence including electroluminescence, (organic and inorganic) cathodoluminescence, and photoluminescence.
b. Investigations on the materials, devices, and tools that will lead to the development of displays on flexible substrates.
c. Studies of micro-mechanics that impact display devices.
d. Investigation of light modulation materials and devices.

Technical Points of Contact: Dr. David Morton, david.c.morton10.civ@mail.mil, (301) 394-1916 or Dr. Eric Forsythe, eric.w.forsythe.civ@mail.mil, (301) 394-0606.

1.3.8. Flexible opto-electronic materials and devices. The ARL requires research investigations into novel materials and devices for opto-electronic applications that includes, thin film transistors, diodes, electronic components for flexible electronic applications. In addition, materials and device research is sought for photovoltaic and other energy harvesting electronic applications. The research in materials and devices shall include relevant basic physics studies that couple electrical, optical and mechanical properties of these materials and devices. Research and study are needed to ensure that the opto-electronic devices for the current and new systems will provide improved performance that is required to carry out complex military missions. ARL is interested in receiving novel proposals that address the technical barriers associated with improving the current state of the art in flexible opto-electronic materials, devices, and components used as the basis for Army systems. Technical areas of interest include, but are not limited to, the following:

a. Theoretical and experimental studies of electronic properties including; carrier transport, carrier mobility, carrier injection, electronic performance and stability. The device shall be based on organic materials, inorganic materials and/or organic/inorganic hybrid materials.
b. Investigations on the materials, devices, and tools that will lead to the development of thin film transistors, diodes, electronic components (capacitors, resistors) required to enable electronic architectures on flexible substrates. The device shall be based on organic materials, inorganic materials and/or organic/inorganic hybrid materials.
c. Investigations on the materials, devices, and tools that will lead to the development of photovoltaic devices solar cells, and related energy harvesting devices on rigid and flexible substrates. The device shall be based on organic materials, inorganic materials and/or organic/inorganic hybrid materials.
d. Studies of micro-mechanics that impact the opto-electronic devices.

Technical Point of Contact: Dr. Eric Forsythe, eric.w.forsythe.civ@mail.mil, (301) 394-0606.

1.3.9 Nonlinear Optics. The ARL requires research investigations and proposals in nonlinear optical (NLO) materials, components and devices that can reduce their optical transmission

across the visible and NIR (400-900nm) wavelength range passively when subjected to an incident laser beam within that wavelength range. Reductions of optical transmission on the order of 1000X or greater is desired. The speed at which such materials, components, or devices switch from transmissive to non-transmissive states needs to be on the order of <1ns. Materials and devices must be highly transmissive in the initial state. Concepts need to be able to be incorporated into low F/# optical viewing systems, yet must not greatly impact the normal performance of those systems. Technical areas of interest include, but are not limited to, the following:

a. Development of optical materials with large nonlinearities and a broad wavelength and/or pulsewidth response. This can include molecular modeling, material synthesis, and characterization of nonlinear parameters as well as nonlinear transmission studies.
b. Modeling efforts to relate nonlinear material properties to their ability to effectively reduce transmission. Modeling effort should include details on how the nonlinear materials affect the propagation of incoming laser beams.
c. Development of optical viewing systems and components that incorporate the materials and devices above.

Proposals utilizing solutions other than NLO materials that suggest novel methods of reducing transmission will also be considered.

Technical Point of Contact: Mr. Andy Mott, andrew.g.mott.civ@mail.mil, (301) 394-0942.

1.3.10. Biologically Inspired and Biologically Derived Sensor, Power, Device and Materials Research. Natural evolutionary processes that organize functionality of biological systems could be considered the pinnacle of engineering science. This capability combined with our initial steps to understand how nature uses evolution to create structures and functionality through the advent of modern biotechnology has ushered in an unprecedented ability to manipulate biological components and organisms. These developments could provide researchers a new paradigm for development of revolutionary photonics, electronics, organic-electronic hybrid devices and sensors. In an effort to capitalize on these advances, targeted investigations will be conducted in the following areas:

a. Biosensors to either sense biology or sense with biology.
b. Biomimetic sensors.
c. Photonic and electronic devices which replicate/mimic or harness biology to function;
d. Biologically derived or inspired power generation and storage.
e. Bioelectronics that are built from biological structures or assembled/enabled by biological structures. Inclusive in these efforts will be the development of new characterization methodologies (spectroscopy and metrology) geared specifically to investigations of organic and hybrid inorganic–organic material properties.

Technical Points of Contact: Dr. Paul M. Pellegrino, paul.m.pellegrino.civ@mail.mil, (301) 394-2030 or Dr. James Sumner, james.j.sumner4.civ@mail.mil, (301-394-0252.

1.3.11. Advanced Concepts for Hazardous Material Sensing Applications. The ARL is exploring new enabling detection technologies for hazardous material sensing applications. The ultimate goal of our research efforts is to develop sensors (both point and standoff) of hazardous

substances for field use. The areas of potential application include, but are not limited to, food/water safety and defense, toxic industrial chemical (TIC) and toxic industrial material (TIM) sensing, improvised explosive devices (IED) detection, unexploded ordinance (UXO) and chemical and biological defense. Desirable features of sensor systems include: high specificity in analyte identification, small in size for field portability, low power requirements, low cost, and stability for long periods of time under various environmental conditions. The several key sensor research thrust areas are transduction technique, biological or chemical recognition, and direct spectroscopic methodologies. Our current research interests include development of both point and remote sensing for hazardous materials using synthetic molecular recognition elements, and optical and electrochemical transduction technologies. The desired sensor technologies are not limited to these methods, but may use mechanical or other novel detection methods. Recognition technologies include, but are not limited to, molecular imprinting, ssDNA hydribization, dsDNA hydribization, aptamers, peptides and phage or cell surface display technologies. Optical technologies include, but are not limited to, new optical sources and detectors for sensors, fiber optics, interferometry, non-linear optics, photonics devices, Raman techniques, and fluorescence. Electrochemical technologies include, but are not limited to, AC voltametry, AC impedance and cyclic voltametry techniques.

Technical Point of Contact: Dr. Paul M. Pellegrino, paul.m.pellegrino.civ@mail.mil, (301) 394-2030.

1.3.12. Visual Signature Management *. Proposals are requested that examine methods to reduce the visual and near infrared (NIR) signature of ground vehicles, rotorcraft and/or soldiers.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

1.3.13. Temperature Control and Heat Transfer (Low Observable)*. Proposals are requested that examine innovative methods to control the radiant power from vehicles and aircraft by modification of radiometric properties and/or heat transfer control of internal combustion engines and heat-producing machinery. The electromagnetic (EM) region of interest is 16 to 2.0 microns.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

1.4 Energy Materials and Components

1.4.1. Electrochemical Power Production and Energy Storage. The areas of interest are:

a. Active and Reserve Primary Batteries for Munitions Applications: Research of new battery chemistries, materials, and battery designs for improved thermal and liquid-electrolyte reserve batteries capable of supplying power densities from 20 to 400 Watts/liter after 10 or more years of storage. Primary areas of interest are: thin-film thermal battery chemistries, materials, components, or production methodologies for thin-film batteries with faster activation, higher power, smaller volume, more-flexible

form-factor, greater mechanical robustness, or better production efficiency; and new forms of heat sources that would be compatible with the thin-film thermal battery technology. Storage and operation are required over the full military temperature range.

b. Primary Lithium Batteries: Research of battery chemistries for cells and stacks of cells for man-portable applications using environmentally-friendly materials capable of providing better service than the Army's present general-purpose Li/SO2 and Li/MnO2 batteries. Emphasis is on modification of commercially-based chemistries to permit all-weather storage and use. This may include Li/air, Li/S and Li/CFx formulations. The development of manufacturing technology for these batteries is an area of interest.
c. Rechargeable Li (Li Ion) Batteries: Research of electrode and electrolyte materials chemistries for cells and stacks of cells using liquid or polymeric electrolytes capable of providing, at the packaged cell level, specific energies greater than 250 Wh/kg, specific power greater than 50 W/kg continuous, and greater than 10 kW/kg pulse power over the full military temperature range. The development of manufacturing technology for these batteries is an area of interest.
d. Fuel Cells: Research and development of improved low temperature alkaline and acid based polymer electrolyte membrane fuel cells and components including catalysts for use with alcohol and solid fuels. Use modeling and simulations to solve and improve fuel cells performance. The development of hydrocarbon fuel reformers and reformer components, including desulfurizers and sulfur tolerant reformer catalysts to provide hydrogen for fuel cells are areas of interest. The development of medium and high temperature fuel cells and components for the direct utilization of hydrocarbon fuels or impure hydrogen is also an area of interest.
e. Fast Discharge Pulse Power Capacitors: Research of film capacitor technology including the development of high energy density dielectric films, impregnants, metallization and manufacturing technology for capacitors that can provide energy densities > 2.0 J/cc with a DC life over 2000 hours, and discharge time is the microseconds range.
f. High Temperature Capacitors for Power Electronics: Research and development of high temperature polymeric dielectrics including process development for high temperature thin film manufacturing. The capacitors made of such thin film dielectric should be operable at temperatures over 125 degrees C, preferably over 150 degrees C. The capacitors shall have the following characteristics: a dissipation factor below 0.5 percent, insulation resistance greater than 105 ohm-farad at 125 oC, operational life of greater than 10,000 hours at frequency greater than 20 kHz and rms current greater than 1.0 A/microfarad.
g. Energy Science: Research and development of novel materials and routes to energy. These could include development of alternative routes to fuel such as direct photoelectrolytic routes to hydrogen or energy, photovoltaic devices that have very high efficiency for development of devices suitable for portable power, can also include metamaterials that could be used in catalysis, high efficiency solar or waste heat to energy. Other routes for waste heat to energy include thermoelectric and thermophotovoltaic devices.

Technical Point of Contact: Dr. Cynthia Lundgren, cynthia.a.lundgren2.civ@mail.mil, (301) 394-2541.

1.4.2. Power Conditioning. The Army is searching for innovative technologies and techniques for reducing the size, weight, cost, and logistics footprint of power conditioning systems across the full range of Army applications. High efficiency and high temperature operation (for reduced cooling) are also critical requirements. Some specific areas of interest include:

a. Novel power converters.
b. Novel materials and designs for high-temperature power conditioning capacitors and inductors.
c. High performance components such as switches and capacitors.
d. Pulse Forming Network (PFNs) and power conversion technology for electric guns, directed energy, electromagnetic armor and other high power and high voltage loads.

Technical Point of Contact: Mr. Skip Scozzie, charles.j.scozzie.civ@mail.mil (301) 394-5211 or Mr. Bruce Geil, bruce.r.geil.civ@mail.mil, (301)394-3190.

1.4.3. Wide Band-Gap Power Devices. ARL is seeking proposals for research of wide band gap devices in the following areas:

a. Device design and fabrication of monolithic and hybrid voltage-controlled SiC or GaN high-temperature high-field power devices.
b. Circuit design and fabrication of highly-efficient Si-based and SiC- or GaN-based high-temperature power electronics for power conversion and motor-control applications.
c. Circuit simulation to allow topology and device trade off studies for the design of high-temperature power conversion circuits for specific Army Future Combat Systems applications.
d. High-temperature high-field insulator materials for use as gate dielectric and field passivation layers for application to SiC and/or GaN power devices.
e. High-temperature packaging and thermal management systems for wide bandgap power electronics (Tj = 225 to 400 C).

Technical Points of Contact: Mr. Skip Scozzie, charles.j.scozzie.civ@mail.mil, (301) 394-5211 or Dr. Aivars Leslis, aivars.j.lelis.civ.@mail.mil, (301) 394-5426

1.4.4. Microsystems Technology for Power Generation and Energy Conversion Components. The areas of technology of interest to ARL include, but are not limited to, the following:

a. Microfabricated combustors and components for micro fuel cells and small thermal-to-electric converters: research and modeling in catalytic and homogeneous combustion for extreme energy dense, high temperature heat sources.
b. Heat transfer and thermal management: Research and modeling in materials and techniques to remove high heat fluxes from power electronics, improve efficiency of small energy converters, recuperate & repurpose waste heat energy, improve thermal system packaging, improve environmental control units, and understand multi-phase heat transfer fundamental mechanisms.

c. Balance-of-plant component for small heat engines and fuel cells: research in fuel technologies including liquid atomization and micro-fuel pumps. Research in high efficiency air delivery including blowers, fans and pumps.
d. Technologies to support microfabricated rotary systems including bearings, motors and similar components.
e. Microsystems power components and conversion: research in high power density, multifunctional components and sub-systems for capturing, transforming, converting and delivering power to microsystems.

Technical Point of Contact: Dr. Brian Morgan, brian.c.morgan25.civ@mail.mil, (301) 394-0926, or Dr. C. Mike Waits, christopher.m.waits.civ@mail.mil, (301) 394-0057.

1.4.5 Ultra-Energetic Materials and Energy Storage. The areas of technology of interest to ARL include, but are not limited to, the following:

a. Radioisotopes and Nuclear Isomers: Develop and study approaches to the control of nuclear emission and/or nuclear decay rates. Investigate nuclear structure of isomeric nuclei, particularly focused on long-lived isomers from which gamma or charged-particle emission could be utilized for power sources.
b. Radioisotope/Nuclear Isomer Energy Conversion: Develop and study improved concepts for conversion of nuclear decays into usable electrical power. Techniques using liquids or novel materials are of interest for long-lived micro-power sources.

Technical Point of Contact: Dr. Marc S. Litz, marc.s.litz.civ@mail.mil, (301) 394-5556, or Dr. James Carroll, james.j.carroll99.civ@mail.mil, (301) 394-1411.

1.4.6 Nuclear Detection and Sensors. Develop and study approaches that include compact sensors that can be arrayed for large area survey and data fusion. Investigate sensor element architectures that enhance system energy efficiency supporting 100 microwatt power level sources and increased performance of compact devices.

Technical Point of Contact: Dr. Marc S. Litz, marc.s.litz.civ@mail.mil, (301) 394-5556, or Dr. James Carroll, james.j.carroll99.civ@mail.mil, (301) 394-1411.

1.4.7 Superconducting Materials. The areas of technology of interest to ARL include, but are not limited to, the following:

a. Materials development of high temperature superconductors. Research for better understanding on structure-property relationship in critical superconducting temperature, superconducting critical current density, and the interaction with external magnetic field. Investigation of pinning effect on superconductivity, transient phenomena of electric current in the superconductor, and the associated ac losses.
b. Investigation of superconductor materials growth mechanism at the interface of the joint. Development of related superconductor processing technology.
c. Devices and applications of superconductors for Army utility.

d. Electronic device development with superconducting materials as component for function and performance enhancement.

Technical Point of Contact: Dr. Paul N Barnes, paul.n.barnes.civ@mail.mil, (301) 394-0039.

b. CORE COMPETENCY 2: BALLISTICS & AEROMECHANIC SCIENCES

2.1 Energetics and Propulsion Science

2.1.1. Novel Insensitive Energetic Materials. ARL is seeking proposals for high quality research and development in novel energetic materials technology. There is interest in low cost, higher performance, and insensitive novel energetic materials technologies to enable energy release tailoring, performance, and acceptable vulnerability characteristics for a wide range of future gun, missile, and warhead munitions. Novel energetic materials formulations and associated technologies support insensitive munitions requirements that will enable munitions to reliably fulfill their performance, readiness and operational requirements on demand, but minimize the probability of inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems and personnel when subjected to unplanned stimuli. Proposals may impact munitions currently used within fielded systems or future munitions, subsystems, or support items. Some examples of areas of interest and emphasis include, but are not limited to, the following: novel propellant and explosive formulations, new crystals/molecules, nano-technology material, advanced binders and energetic polymers, desensitization technologies, metastable compounds, reactive materials, energetic structural materials, activated metal powders, hydrides, novel energy releasing processes and mechanisms, ignition and initiation, wear and erosion, modeling and simulation, advanced diagnostics and testing methods, and detection methodologies. Proposals are also sought that address novel energetic materials and formulations in conjunction with munitions system design and packaging. Some examples of areas of interest and emphasis include, but are not limited to: liner materials, passive/active venting, coatings, thermal protection materials, and barrier/ballistics material.

Technical Points of Contact:
Dr. Brad E. Forch, e-mail: brad.e.forch.civ@mail.mil, (410) 306-0929;
Dr. Patrick Baker, e-mail: patrick.j.baker26.civ@mail.mil, (410) 278-6800

2.1.2. Laser-matter Interactions. In conjunction with other Army and DoD efforts into studying directed energy (DE), nonlinear optics (NLO) and ultrashort pulse lasers (USPL), ARL seeks to prepare the basic understanding of physical processes for future applications of these developing technologies. These technologies are approached from two viewpoints: application of energy, and protection from effects. Interests include, but are not limited to:

a. Extension of studies, experimental and theoretical, into developing regimes of USPL radiation sources. Specifically, we seek to advance the knowledge from 800 nm to 1.5-2.5 μm and UV wavelengths while comparing advantages and disadvantages. This will include differences in nonlinear propagation, propagation in adverse conditions, and solid target interactions.

b. Interaction of USPL and short pulse lasers with air molecules. This research entails theoretical and experimental analysis of intense electromagnetic (EM) fields with diatomic molecules below, at, and above the ionization threshold. As well, examine the role of different wavelengths and pulse durations on these effects.
c. Design and performance of novel nonlinear optical devices to enhance imaging, laser direction, laser contrast, and laser beam quality. Utilizing new concepts, materials, and applications we look for the physical understanding to radically alter how we are able to sense, protect from, and direct EM radiation with the emphasis on higher efficiencies, lower cooling demand, and smaller and lighter devices.
d. Coupling of DE with other forms of EM and mechanical energy. Examine the interaction of DE, USPL and solid matter to produce enhanced effects in air and target materials. This research seeks to resolve how different energy types couple and interact, and how the combined effect of coupled energy influences the material properties of the media in which the energy is combined. Examples include enhancement of NLO effects in air by heating with a second, coupled laser source, or weakening target materials with lasers to render them less resistant to mechanical impact. An understanding of the timescales of interaction events and material changes produced in the target media (both chemical and physical) by different types of combined energy as well as a strong theoretical understanding is required to tailor energy interactions with various media to achieve desired effects.

Technical Points of Contact:
Dr. Anthony Valenzuela, email: anthony.r.valenzuela6.civ@mail.mil, (410) 278-9876
Dr. Chase Munson, email: chase.a.munson.civ@mail.mil, (410) 278-1369

2.1.3. Engine Technologies. Advanced engine cycles, aero and mechanical components, and concepts for improving the engine performance & reliability of ground and air systems while reducing weight & cost. Analytical code development supported by complementary experimental validation testing of components.

Technical Point of Contact: Dr. Chol-Bum "Mike" Kweon, email: chol-bum.m.kweon2.civ@mail.mil, 410-278-9319.

2.1.4. Drive Train Technologies. Advanced drivetrain technologies for high-temperature, high-speed, lightweight, reliable and efficient mechanical power transfer systems of ground and air vehicles. Analysis code & algorithm development supported by experimental validation testing of components.

Technical Point of Contact: Dr. Brian Dykas PE, email: brian.d.dykas.civ@mail.mil, 410-278-9545.

2.1.5. Rotorcraft Research. Advanced gas turbine engine and mechanical power transfer system technologies and concepts for improving performance & reliability while reducing weight & cost of propulsion systems for rotorcraft vehicles. Analysis code & algorithm development supported by experimental validation testing of components.

Technical Point of Contact: LTC David "Blake" Stringer, PhD, email: david.b.stringer.mil@mail.mil, 216-433-8482.

2.1.6. Thermal and Propulsion Materials and Components. High-temperature materials and structures research for advanced propulsion concepts to improve engine performance and reliability while reducing weight and cost. Analysis and experimentation with candidate high-temperature materials and structures including evaluation of processing and lifing of sub-elements and components.

Technical Point of Contact: LTC David "Blake" Stringer, PhD, email: david.b.stringer.mil@mail.mil, 216-433-8482.

2.2 Impact Physics

2.2.1. Warhead Technology. Proposals are sought for research and development of topics related to advanced warhead technologies. Of specific interest are multi-functional warheads and scalable warheads for application in all classes of weapon systems and for use in all environments. Areas of interest include experimental, computational, fragmentation, blast, shaped charges, explosively formed penetrators, energetic materials that can be used in a multi-purpose fashion, lethal mechanism integration, and application against urban structures (such as creating large holes in walls).

Technical Point of Contact: Mr. Tim Farrand, email: timothy.g.farrand.civ@mail.mil, (410) 278-6065.

2.2.2. Human Incapacitation – Penetration of Soft Tissue. ARL conducts an extensive applied research program in human incapacitation and wound ballistics. There is interest in low cost, high performance materials and materiel for use in barrier and body armor applications. Proposals for modeling and simulation and/or experimental validation are sought that address ballistic interaction with metal, glass, composite, or other barrier materials, vehicle armor, individual body armor, and the penetration of, and trauma to, soft tissue(s). Proposals may impact lethality and/or survivability aspects of small caliber and medium/large caliber fragment-producing munitions currently in use within fielded systems or future munitions, subsystems, or support items, as well as the defeat of these threats by the individual warfighter.

Technical Point of Contact: Dr. James Newill, e-mail: james.f.newill.civ@mail.mil, (410) 278-6097

2.2.3. Armor Technology for Warhead Defeat. Proposals are sought for research and development of advanced armor technologies for warhead defeat. Warheads of interest include shaped charges such as seen in rocket propelled grenades (RPGs) and anti-tank guided missiles (ATGMs), as well as explosively formed penetrators (EFPs). Areas of interest include novel passive, reactive, and electromagnetic armor technologies.

Technical Point of Contact: Mr. John Runyeon, email: john.w.runyeon.civ@mail.mil, (410) 278-6568.

2.2.4. Early Detection and Vehicle Response to Underbody Blast Events

a. Advanced Methodologies and Instrumentation for the Detection of Underbody Blast Events. Conduct applied research and advanced development to create enhanced capabilities for detecting the occurrence of an underbody blast event prior to vehicle impingement. Areas of interest include methodology, sensors, data acquisition, signal conditioning, filtering, fusion techniques, modeling and simulation, all focused on providing a high probability of detect (PoD) combined with a low probability of false alarm (FA) across a wide range of operating conditions. Proposed technologies must be robust across a wide range of underbody threats.
b. Advanced Methodologies and Instrumentation for the Measurement of Vehicle Response to Underbody Blast Events. Conduct applied research and advanced development to create enhanced capabilities for measuring vehicle reaction to an underbody blast event. The area of interest includes the measurement of vehicle dynamics in response to underbody events. Due to the extreme environment coupled with a wide variety of time scales (from sub-microsecond shock loading to multiple second rigid body motion), traditional methods, such as IMUs, do not provide accurate positional tracking through these blast events. An absolute measurement technology is preferred as opposed to a method that relies upon numerical integration and should provide a high-fidelity state determination solution (6DoF) for the vehicle crew compartment during the entire blast event.

Technical Points of Contact:
Mr. Neil Gniazdowski, email: neil.m.gniazdowski.civ@mail.mil, (410) 278-6058.
Mr. David Lyon, email: david.h.lyon.civ@mail.mil, (410) 306-0980.

2.3 Aeromechanics

2.3.1. Rotorcraft Aeroelasticity. Analytical and experimental capabilities to support development of advanced numerical methods and computational codes for assessing aeroelastic, aeromechanical, and structural dynamics performance.

Technical Point of Contact: Mr. Matthew Wilbur, email: matthew.l.wilbur.civ@mail.mil, 757-864-1268.

2.3.2. Vehicle Dynamics. Analytical techniques for predicting structural dynamics and aeromechanical response of advanced vehicle concepts including real-time active, adaptive suspension system with preview sensor-driven control algorithms.

Technical Point of Contact: Dr. Muthuvel Murugan, email: muthuvel.murugan.civ@mail.mil, 410-278-7903

2.3.3. Vehicle Integrated Analysis Technologies. Fundamental technology analysis capabilities needed to model vehicles and their components. Research tools for understanding and

developing the ability to couple physics-based analyses to assess full-spectrum military operations.

Technical Point of Contact: Dr. Rajneesh Singh, email: rajneesh.k.singh.civ@mail.mil, 410-278-4022.

2.3.4. Affordable Precision Munition Technologies. ARL conducts an extensive applied research program in support of technologies that enable affordable precision munitions. Research interests include guidance laws, guidance sensors, navigation methods, control laws, maneuver actuators, aerodynamics, flight dynamics, experimental research, technology development, and prototype demonstrations that expand the body of knowledge and understanding in these areas.

Technical Point Contact: Mr. David Lyon, e-mail: david.h.lyon.civ@mail.mil, (410) 306-0980

2.4 Ballistic Vulnerability

2.4.1. Weapons Effectiveness. ARL is conducting an extensive fundamental research program in support of improving weapon effectiveness. This topic encompasses a diverse spectrum of weapons and systems, including small, medium, and large caliber gun-launched systems; rocket and missiles; hybrid gun-missile concepts; direct-fire and indirect fire weapons (LOS, NLOS, BLOS); smart munitions, munitions guidance, navigation, and control (GN&C), and high g-hardened gun-launch technologies; energetic materials development; interior, transitional, and exterior ballistics; ballistic wear and erosion, defensive weapons and systems such as active protection and extended area protection; non-lethal weapons technologies; robotic platforms, unmanned aerial vehicles (UAV), unmanned ground vehicles (UGV), including hardware, command and control algorithm development, behavior modeling and simulation, and operations in semi-autonomous, near-autonomous, and fully autonomous modes. Proposals may address improving weapon effectiveness of existing systems or new concepts, as well as tactical use of weapons, such as under conventional battlefield conditions, in military operations in urban terrain, or in non-military homeland defense applications for Federal or local law enforcement agencies. Proposed research can be in modeling and simulation, experimental in nature, or both.

Technical Point of Contact: Dr. William Oberle, e-mail: william.f.oberle.civ@mail.mil, (410) 278-4362

2.4.2. Fundamental Basis for Survivable Systems Subjected to Multi-physics, Multi-phase Asymmetric Threats. For traditional force on force battlefields, the protection requirements for armored vehicles, soldiers, and other Army assets were based primarily on conventional war concepts and threats. However, asymmetric battles have shown that the protection is required on all types of military and civilian structures, and encompass a wide variety of both conventional and unconventional threats, such as kinetic energy projectiles, IEDs (roadside, buried, vehicle-born, and suicide Improvised Explosive Devices), grenades, missiles, and mines. In addition, the battlefield in which these assets operate includes complex urban terrains and the United States homeland. Proposals are requested to conduct a broad, interdisciplinary basic research program to develop advanced science and engineering based methodologies that afford advanced

understanding of crew and vehicle survivability under unpredictable explosive-device induced blasts. To date the fundamental underlying mechanisms that challenge the survivability of critical Army/civilian structures and systems with respect to the unconventional explosive threats is not well understood. This highly multidisciplinary research area includes complex interactions between terrains, explosives, and extremely hard to extremely soft material systems. Modeling unconventional blast-effects on structures requires a two-step process:

a. The first step is modeling of the blast itself resulting in a multi-phase flow, which requires improved physical understanding of detonation processes as well as their packaging and the environmental conditions. Modeling and characterization of the dynamic behavior of a wide range of explosive packaging methods including combinations of soils, pavement overlays, metal, and other encapsulations result in extreme spatial and temporal pressure gradients and fragment distributions. Fine scale temporal and spatial resolutions are needed to achieve a threshold level of predictive capability. It is essential to accurately model the explosion/combustion reaction chemistry to deal with the issues surrounding reacting multi-phase flow from metallized blast explosives (using aluminum, higher density metal fuels, and/or thermites, etc). Turbulent mixing, combustion, and reaction chemistry (both during the detonation and fireball formation) need to be addressed. The capability to independently represent both the fluid and solid components so they can be coupled to and applied to the structure in a realistic manner is essential.
b. The second step of the two-step process is to model the effects of explosive systems on military and civilian structures. This requires parallel, explicit, Lagrangian codes with a library of continuum and structural elements, robust parallel contact algorithms capable of dealing with explosively driven deformations, and adaptive techniques to capture the physics of localization and subsequent failure. The design optimization of explosive systems and their effects involves problems that are geometrically and materially nonlinear. Fracture and fragmentation of large military and civilian systems involves a variety of spatial and temporal scales from nanometers to meters and microseconds to seconds. Two important effects of explosive systems and other kinetic energy penetrators on Army systems is the generation, and dispersion of stress waves through complex material configurations and the formation of highly lethal behind armor debris.
c. The final area of need is to develop tailored materials (novel metal laminates/ advanced metallic-composite) for enhanced survival from explosive systems. Finite Element tools need to be utilized to develop design guidelines that provide yield strength, ductility, modulus, etc. parameters necessary for fabrication. As materials are developed, test and evaluation methods need to develop methods for imbedded/organic diagnostics to monitor dynamic material properties as samples are evaluated in order to verify and improve material models.

Technical Point of Contact: Mr. Neil Gniazdowski, email: neil.m.gniazdowski.civ@mail.mil, (410) 278-6058.

c. CORE COMPETENCY 3: INFORMATION SCIENCES

3.1 Network Sciences

3.1.1. Network Theory. The ARL is interested in receiving proposals addressing the technology and technical barriers for extending the state of the art of fundamental network science as it applies to tactical networks and communication requirements. This includes the study of interactions of communications, information, and socio-cognitive (CIS) networks, and the development of analytical models of dynamic network flows, resulting in novel theories and tools. Research interests include, but are not limited to advancing the state of the art in the following research areas:

a. Novel mathematical representations and analysis of dynamic networks as a path to understanding and characterizing structure and evolution of network topologies.
b. Establishment of fundamental limits and tradeoffs for information flows in multi-genre networks, and development and analysis of protocols.
c. Models for the impact of dynamic network processes on network structure and vice-versa
d. Controlling global topology and behavior of information flows via local interactions.

Technical Point of Contact: Dr. Brian Rivera, email: brian.m.rivera.civ@mail.mil, phone: 301-394-2298 and Dr. Ananthram Swami, email: ananthram.swami.civ@mail.mil, phone: 301-394-2486.

3.1.2. Secure Wireless Mobile Communications. The ARL is interested in receiving proposals that address science and technology for mobile wireless communications networks, especially the mobile tactical domain, and including sensor networks. The objectives of this research are to enable secure, survivable and assured communications over wireless networks among highly mobile users, sensors, and robotic platforms under adverse channel conditions, with desired quality of service on demand. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

a. Bandwidth and energy constrained mobile transceiver design.
b. Cross-layer designs, especially with respect to physical layer and media access layer interaction.
c. Multi-antenna methods, including space-time processing, for mitigating multi-user and intentional interference, while achieving very high capacity.
d. Techniques for overcoming electronic warfare and jamming threats.
e. Dynamic spectrum access, and frequency agile systems.
f. The combination of channel equalization and coding techniques.
g. Wideband modulation methods such as orthogonal frequency division multiplexing.
h. Ultra wideband systems, including coexistence issues and system overlays.
i. Sensor networking systems, including signal processing and communications interactions, distributed detection and estimation, and networking protocols.
j. Ad hoc mobile networking protocols and procedures.
k. Survivable wireless and hybrid cell based ad hoc networks and networking.

l. Key distribution and security in a mobile wireless ad hoc network.
m. Automating creation and distribution of interoperable vulnerability knowledge bases.
n. Network management and visualization tools that support real time planning and control of tactical networks.

Technical point of contact: Dr. Brian M. Sadler, email: brian.m.sadler6.civ@mail.mil, phone: 301-394-1239 and Dr. Brian Rivera, email: brian.m.rivera.civ@mail.mil, phone: 301-394-2298.

3.1.3. Sensor Network Communications. The ARL is developing communications devices and technologies for unattended sensors. These unattended devices must work for long periods on limited battery power, use Anti-Jam and Low Probability of Detection waveforms, perform ad-hoc networking for autonomous self-healing routing, and provide network security for authentication, data integrity and privacy. ARL is also interested in leveraging these technologies for use in other energy constrained communications applications. Areas of interest include, but are not limited to:

a. Ad-hoc network protocols.
b. Security protocols.
c. Robust AJ/LPD waveforms.
d. Energy efficient modems.
e. Energy efficient RF front-ends and components.
f. Low power signal processing.
g. Small broadband antenna.
h. Forward-error-correction.
i. Integration of sensor and communications processing.
j. Efficient integration of sensor and communications into Unattended Sensors.

Technical Point of Contact: Mr. Ronald G. Tobin, e-mail: ronald.g.tobin.civ@mail.mil, phone: 301-394-2184.

3.1.4. Cyber Defense and Information Assurance. The ARL is interested in receiving proposals that address the technology and technical barriers for improving the state of the art of critical scientific areas that affect cyber defense and information assurance for wired/wireless networks. The objective of the research is to strengthen the underlying science of cyber defense and intrusion detection. Research interests include, but should not be limited to, advancing the state of the art in the following research areas:

a. Applicability, impact, and implications of ensemble techniques to examine existing anomaly-based intrusion detection techniques at a fundamental level.
b. Fundamentals of visualization for cyber security for the exploration, analysis, and situational awareness of network events to deal with the sheer volume and complexity of the data.
c. Decision theory and online learning of intrusion detection for the minimization of costs to detect and prevent intrusions using network monitors by analyzing a more accurate model of the flows in and among networked hosts.

d. Automating intrusion monitor placement for 1) dynamic probing and sampling for intrusion detection in large cyber systems under resource constraints and 2) anomaly localization based on a quickest detection approach.

Technical Point of Contact: Mr. Curtis B. Arnold, email: curtis.b.arnold.civ@mail.mil, phone: 301-394-0263 and Dr. Robert F. Erbacher, email: robert.f.erbacher.civ@mail.mil, phone: 301-394-1674.

3.1.5. Unattended Ground Sensor (UGS) Technology. Technology concepts, sensors, algorithms, and hardware modules that support:

a. Wide-area detection, localization, classification and identification of people, ground vehicles, aircraft, and ammunition fire (e.g., gunshots, mortar, artillery, etc).
b. Autonomous determination of accurate position, orientation, localization and field deployment of UGS.
c. Smart mine sensor field surveillance.
d. Communication, networking and distributed fusion of information among various UGS nodes to provide robust ISR information.
e. Remote control of UGS. Of particular interest are low-cost, low-powered, and small-sized hardware modules that implement the functions listed above.

These UGS should be capable of low-altitude air deployment. Issues relevant to variations in dispersion area, terrain, etc are critical.

Technical Point of Contact: Mr. Tom Walker, Thomas.w.walker68.civ@mail.mil, (301) 394-0756.

3.1.6. Disposable Sensor Technology. Research proposals are desired that can lead to a complete sensor system consisting of several disposable sensor nodes that can communicate with a remote display. Each disposable sensor node should include one (or more) transducer(s), a signal processor, and a communication device, all in a single package. Disposable sensor nodes should be extremely small, lightweight, and consume extremely low amounts of power. The projected unit cost for individual nodes should be less than $10 each, based on production quantities in the millions.

The primary performance goal is the detection of personnel and/or human activities, especially in confined areas; e.g., buildings, caves, bunkers, tunnels, sewers, etc. False-alarm rates must be kept low, even in a dynamic battlefield environment. In general, overall network performance is more important than performance metrics for individual nodes: “the network is the sensor”. Other desirable performance goals include detection and/or classification of other targets and/or threats, including gunshots, mortar, artillery, and rocket launches and/or explosions; power line activity; telephone activity; chemical and/or biological threats; unattended air vehicles, micro-air vehicles, and other robotic or autonomous vehicles; etc. Low-bandwidth information, including context-oriented location information, should be exfiltrated via the sensor network to the end user in near-real time. Sensor modalities are not specified in this topic, but could include acoustic, seismic, magnetic, electric field, non-imaging passive infrared, passive RF, chemical/biological, and/or any other transducer(s) that could be used to detect any targets or threats of military significance. Sensors should be chosen and/or configurable for a wide variety

of Intelligence, Surveillance, and Reconnaissance (ISR) missions, including self-protection for individual soldiers, surveillance by small groups of soldiers, perimeter security, and border monitoring.

Node-level computations are needed to reduce relatively high-bandwidth raw sensor data to immediately usable information that can be transmitted over extremely low-bandwidth ad hoc sensor networks. The sensor output should be as concise as possible, but include a node ID, timestamp, target type, and confidence level. Development of sensor fusion algorithms, including multi-modal algorithms that are independent of particular transducers, can be considered under this topic.

The communications source may be acoustic/ultrasonic, RF, or IR, or it may resonate or reflect "on command" from an external receiver. One-way communication may be used to exfiltrate data to end-users and/or more capable sensors, gateways, etc. The network should be able to infer node location information from some combination of the ISR sensors, the network topology, and/or programming during emplacement. The node reports should include contextual location information; localization should not depend on GPS. The problem of exfiltrating data from confined areas, e.g., through robust multi-hop networking, should be addressed.

Sensors should be deployable by hand, via UAVs, helicopters, and/or cargo rounds (artillery); however, high-G packaging techniques are not a focus of this topic. Similarly, proposals submitted under this topic should NOT focus on sensor information assurance, network-level information fusion, novel low-cost sensor technologies, low-power microprocessors, communications and networking theory, novel display technologies, haptic interfaces, low-cost packaging for high-volume production, and/or power and energy technology (i.e., batteries). These are important issues, and components using technology from all of these areas could be part of a proposed sensor system; however, funding to advance these technologies will generally not be funded under this topic.

Technical Point of Contact: Mr. Jeff Houser, Jeffrey.g.houser.civ@mail.mil, 301-394-0797.

3.2 Decision Support Sciences

3.2.1. Information Science and Technology. The ARL is interested in basic and applied research resulting in technologies that support state-of-the-art capabilities for the Warfighter in the analysis, assimilation, and dissemination of battle space information. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

a. Natural language processing.
b. Intelligent software agents.
c. Automated information distribution.
d. Information fusion and visualization.
e. Knowledge discovery.
f. Social network analysis.
g. Automated human language translation using text and speech data.
h. Mixed small robot/soldier team collaboration and behavior.
i. Autonomous platform software integration including manned and unmanned systems.

Technical Point of Contact: Dr. Barbara Broome, email: barbara.d.broome.civ@mail.mil, phone: 301-394-1956.

3.2.2. Natural Language Processing (NLP). The ARL desires NLP and computational linguistics methods and algorithms to develop and improve technologies for machine translation, information extraction, and automated summarization. Also relevant are methods and algorithms to develop and improve technologies for OCR and speech recognition as input to machine translation, information extraction, and automated summarization. Additionally, ARL requires development of language data in support of building these technologies and development of metrics to evaluate them.

Technical Point of Contact: Dr. Melissa Holland, e-mail: virginia.m.holland6.civ@mail.mil, phone: 301-394-3001

3.2.3. Software Technologies Targeting Interoperability for Systems of Systems. Emerging DoD systems represent a revolutionary leap ahead in the concept of "system of systems" and interdependent operations. Interoperability and the management of complexity is the chief challenge in harnessing technologies to meet the Army's current and future information requirements. Software will provide the glue which ties together all the pieces, and in so doing, must be adaptable, flexible, and agile enough to accommodate the widely disparate and rapidly evolving systems. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

a. Domain-specific modeling languages and semantics.
b. Model-based design and development/engineering for system of systems architectures and ultra large scale software intensive architectures.
c. Models which support reflective (self-referential) capability.
d. Principles and ontology development for organization of components, their design and construction.
e. Verifiably correct generators and models.
f. Re-engineering and Integration technologies (methods, tools, metrics, models, etc.) for legacy systems.

Technical Point of Contact: Mr. Larry J. Tokarcik: email: larry.j.tokarcik.civ@mail.mil, phone: 301-394-5614.

3.2.4. High-level Information Fusion, Exploitation, Social Network Analysis and Knowledge Management Research. The ARL is interested in proposals that address developing in-depth understanding and knowledge of the fundamental science and technology required for improved situational understanding of the decision space. There is a need to develop high-level information fusion, exploitation, and knowledge management systems that require not only the elicitation of human expertise but encoding it in computational formalisms that support the reasoning processes. Automated support for discovering knowledge that aid in the understanding of the human terrain for the tactical Warfighters focused on socio-cultural data collection and processing is required. New and innovative ways to process and visualize related information, such as data mashups, are needed. ARL's interest includes knowledge of heterogeneous data and

multimedia types, data mining, text mining, knowledge agents, knowledge brokers, visual analytics, collaborative knowledge visualization, improved knowledge representation schemas, social network analysis, and the application of cloud computing with the information exploitation process.

Technical Point of Contact: Mr. Mark Thomas, email: mark.a.thomas342.civ@mail.mil, phone: 410-278-5840

3.2.5. RF Phenomenology, Signal Processing and System Design. ARL is interested in RF techniques, concepts, models, algorithms, and hardware modules that support:

a. All-weather, wide-area detection, location, and recognition of stationary tactical ground targets that may be behind walls or concealed in foliage and/or employing camouflage, concealment, and deception.
b. All-weather, wide-area detection, location, and discrimination of surface and near surface buried mines and/or improvised explosive devices.
c. All-weather, wide area detection, location, and tracking of moving targets (e.g., personnel, tactical vehicles and low flying aircraft) from a ground-based and/or airborne foliage penetrating sensor system.
d. The detection of very small RF signals in highly cluttered environments, including active and passive techniques for man-portable, ground vehicle, and airborne platforms.

In particular, research proposals are desired in areas that address the technical obstacles associated with using an ultra-wide frequency band (UWB) synthetic aperture radar (SAR) for the detection, location, and possibly classification of subsurface targets (ranging from near surface to deeply buried objects). Further, proposals are desired to support low frequency radar models, techniques, and enabling component technology. In addition, proposals are sought to support passive and active RF techniques that can detect small signals in highly cluttered environments (i.e. natural and man-made clutter as well as electromagnetic interference). The proposals may address, but are not limited to:

e. Radar component technology, including wide-bandwidth/ low-frequency antennas, high power transmitters, high-speed signal processors, and analog-to-digital converters.
f. Radio frequency interference (RFI) extraction/avoidance techniques including cognitive techniques for interoperability of multiple RF systems in cluttered electromagnetic environments.
g. Optimization of algorithm code.
h. Modeling to support subsurface detection in a variety of environments/soil conditions.
i. Developing techniques to estimate the bulk dielectric constant of and signal loss through wall materials.
j. High-precision position location systems.
k. Radar imaging techniques to mitigate sources of artifacts.
l. Beam-forming techniques.
m. Self-aligning and calibrating arrays.
n. Bistatic system concepts.

o. Target detection, tracking and classification algorithms.

Technical Point of Contact: Dr. Anders Sullivan, anders.j.sullivan.civ@mail.mil, (301) 394-0838.

3.2.6. Image Processing (IP). This topic addresses research interests in algorithm development for image reconstruction, enhancement, detection, recognition, tracking, identification of objects-of-interest and spatiotemporal perception. The data class of interest includes EO-IR-multi/hyperspectral imagery and video. These different types of imagery vary in resolution, wavelength, and sensor type that can be exploited individually or collectively. Applications of interest include persistent surveillance, perception in autonomous systems and decision support systems.

Specific topics include:

a. Model based Automatic Target Recognition (ATR). Algorithms incorporate external knowledge related to the targets, scene, and sensor to perform one or more ATR functions such as detection, recognition, tracking, and identification.
b. Scene understanding and spatiotemporal perception. Beyond conventional ATR in which isolated objects are detected and classified, there is need for identifying relationships among objects and entities in a scene in both space and time where applicable. Identification of behavior and activities is an area of interest. Studies to extend scene classification algorithms by exploiting additional sources of information should be considered.
c. Multisensor IP algorithms. Passive video or FLIR ATR is frequently preferred in a battlefield scenario. However, the increased information content and the potential performance boost of combining passive and active sensors makes multisensor fusion approaches worth investigating. Proposals for the development of algorithms providing fusion of FLIR imagery with one or more sensors, such as ladar, or millimeter wave (MMW), will be considered if they represent a performance enhancement over current methods.
d. Hyperspectral IP algorithms. Information content is increased with use of hyperspectral imagery. Special problems arise because of the large amount of information. Novel methods by which to exploit the increased information content without sacrificing speed of computation are possible topics of research in this area.
e. Image Synthesis and reconstruction. Algorithms for generating images from sensor array data such as antenna arrays, microphones, hyperspectral sensor systems etc. and from partial or incomplete information. Areas include 3D reconstruction, tomographic reconstruction, super-resolution and sparse-sampled processing, high dynamic range synthesis, image graphics, image rendering and display.

Technical Point of Contact: Dr. Raghuveer Rao, raghuveer.m.rao.civ@mail.mil, (301) 394-0860.

3.2.7. Acoustic Technology. Proposals are requested for technology in acoustic sensors and signal processing. Specific areas of interest include (i) advanced acoustic sensors and sensor array designs for UGS and on mobile ground platforms including small robot vehicles and on aerial platforms such as aerostats and UAV's; and (ii) advanced signal processing

techniques/algorithms for multi-target beam forming, target tracking, target classification and identification, reduction of wind noise reduction, reduction of platform noise reduction, etc. Required detection capabilities include continuous sources (vehicles, aircraft, etc.) and impulsive sources (gun fire, artillery impacts, etc.). Other areas of interest include, but are not limited to, long-range hearing, biomimetic acoustics, auditory enhancement of individual soldiers, acoustic signature data collection techniques and equipment, acoustic propagation modeling, novel data analysis techniques, and systems to employ acoustic sensors in new innovative ways, and multi-modal sensor fusion with acoustics and other non-imaging and/or imaging sensors. .

Technical Points of Contact: Mr. Mike Scanlon, michael.v.scanlon2.civ@mail.mil, (301) 394-3081 or Dr. Tien Pham, tien.pham1.civ@mail.mil, (301) 394-4282.

3.2.8. Sniper and Artillery Location Technology. Proposals are requested for research in sensor technology for detecting, tracking and locating the source of hostile small arms, artillery, rocket, and mortar fire. Potential sensors include acoustic, seismic, radar, infrared, and ultra violet. Sensors proposed for this application should be capable of locating the source of enemy fire, and may include other data such as the distance of the miss, the type and number of rounds fired, etc. Source bearing accuracy of better than +/- 10 degrees is desirable.

For small arms, location of the firing source at ranges of 300 m and beyond is desirable. For mortar/artillery/rocket fire, location of likely firing positions despite intervening terrain or non-benign environmental conditions is of particular interest. The capability to locate the source of mortar firings at ranges greater than 2 km and artillery/ rocket firings at ranges greater than 10 km is desirable. Operation of sensors on individual soldiers, fixed sites, and moving vehicles are all of interest. Research into areas either directly addressing the sniper/mortar/artillery/rocket problem or supporting technologies will be considered.

Technical Points of Contact: Mr. Mike Scanlon, michael.v.scanlon2.civ@mail.mil, (301) 394-3081 or Mr. Steve Tenney, stephen.m.tenney2.civ@mail.mil, (301) 394-3080.

3.2.9. Electric Field Sensor Technology. Research proposals are desired that are related to small, rugged, low-power electric field sensors that can be deployed on a battlefield using artillery-based delivery systems, or scattered from air or ground vehicles, or emplaced by individual soldiers. These sensors should be passive or semi-active (i.e., with no local field-generating element), and may operate at low frequencies in the quasi-static zone (or "near field"), where the electric and magnetic fields are not coupled. These sensors should be characterized by exceptionally low power, size, weight, and cost, and/or by exceptionally high sensitivity and low noise (i.e., with performance limited by the background environment).

They should operate in an unattended mode, and should be able to detect, classify, identify, localize, and/or track tactically-significant targets, including ground vehicles (tanks and other tracked vehicles, and wheeled vehicles), air vehicles (fixed-wing, rotary-wing, UAV/MAVs, etc.), and/or other targets and events at tactically-useful distances. These other targets include, but are not limited to, armed individual soldiers, underground facilities, power and telephone lines, RF transmitters; other events including gunshots, mortar and artillery launches, and explosions.

These sensors may be used individually or as part of a wide-area sensor array for surveillance, target acquisition, and/or engagement. While individual sensors may or may not have exceptional individual performance, their low size, power, weight, and cost should permit them to be used on the battlefield in ways not previously contemplated. Moreover, arrays and/or networks of such sensors are expected to provide new sensing capabilities and levels of performance simply not available today.

Unattended surveillance sensors may be stationary or mounted on robotic platforms; these sensors will be integrated with local signal processing and communications capabilities, and should operate unattended for weeks or months after deployment. The sensor output should be quantitative: e.g., analog voltage level(s) or digital word(s); it should contain target information, and possibly a confidence level, suitable for low-bandwidth transmission and/or inter-sensor fusion.

Proposals related to the subject technology are also desired, to the extent that they are applicable to standalone sensors that can be used in proximity fuses, small-unit training and simulation devices, etc. In this case, sensors may operate for a much shorter period of time (typically seconds to hours), so extremely low-power operation is less important, and the final sensor output may be qualitative (yes/no).

Proposals will be accepted in five areas:

a. Research on novel electric field sensor concepts leading to quantification of detection distance(s), classification, identification, localization, and/or tracking of various classes of targets.
b. Research directed at environmental and/or platform noise reduction, and/or reduction of sensor front-end noise (particularly 1/f noise).
c. Research related to filtering and/or signal processing techniques, which are expected to improve the detectability of targets in a battlefield environment.
d. Computer-based modeling of targets and sensors that can provide a capability to perform trade-off analyses of sensor concepts during prototype design.
e. Research of prototype design(s) of individual electric field sensors suitable for detecting tactically significant targets in battlefield environment.

There are several related topics in this BAA that are intended to complement each other. Proposals that focus on magnetic sensing should be submitted against the "Magnetic Sensor Technology" topic. Proposals that focus on low-cost sensor systems should be submitted against the "Disposable Sensor Technology" topic.

Technical Point of Contact: Mr. David M. Hull, david.m.hull6.civ@mail.mil, 301-394-3140.

3.2.10. Passive Magnetic Sensor Technology. Research proposals are sought for work that can lead to small, rugged, low cost, low power, highly sensitive passive magnetic sensors for use as part of unattended ground sensor systems. The sensors can be deployed using artillery, scattered from the air or ground vehicles, or hand emplaced. Since it is desired that they will operate unattended for weeks or months at a time, they must consume very little power. To provide

surveillance over an area of a few square kilometers, many low cost sensors will have to be employed. The sensors may detect ferromagnetic material on vehicles or carried by armed personnel or the low frequency signals generated by vehicles or underground facilities. For most applications, the sensor output should have a digital output that can be used in a tracking/classification algorithm. Magnetic sensors used in some application such as in proximity fuses, small-unit training and simulation devices, etc. may consume more power. Other BAAs cover communications between sensors and to hubs.
Besides using stationary sensors, the sensors also may be employed on robotic platforms, UAVs, and UGVs. In these applications, the requirement of low cost is less severe, but there is a need for coping with noise generated by rotational vibrations. Total field magnetic sensors may provide a solution to this problem. Proposals are sought for:

a. Low cost, energy efficient, high sensitivity vector and total field sensors.
b. Methods for reducing geomagnetic noise.
c. New efficient algorithms for identifying and tracking targets.
d. Methods for reducing the cost and power consumption of magnetic sensors.

Technical Point of Contact: Dr. Alan S. Edelstein, alan.s.edelstein.civ@mail.mil, (301) 394-2162.

3.2.11. Sensor Data and Information Fusion: The Army is interested in fundamental theory of sensor processing and their models to provide the basis for data and information fusion to enhance the probability of detection & classification with minimal false alarms and to achieve a high level confidence in the detection & classification. Research in robust target detection and classification algorithms based on multiple phenomenologies is sought. The Army is interested in data and information fusion algorithms that are robust and well grounded in phenomenology which can be implemented at the node and network levels. There is also interest in techniques and methodologies for determining the quality of information before and after fusion along with the notion of value of information for Intelligence, Surveillance and Reconnaissance (ISR) applications. The Army is seeking scalable fusion architectures that can be used at node level and network level for situational awareness to fuse disparate, multi-modal multi sensor data/information. Fusion methodologies for hard and soft data fusion and algorithms for efficient data dissemination over the network are also sought. The Army is seeking research into sensing methodologies for information gathering rather than data gathering and inferring the adversarial intent.

Technical POC: Dr. Lance Kaplan, lance.m.kaplan.civ@mail.mil, (301) 394-0807.

3.2.12. Technology Demonstrations and Assessments for Special Operations and Low Intensity Conflict (SOLIC). ARL is interested in proposals that focus on demonstrating (prototype level) or assessing (unique facilities) across any of the technical areas described in the Army Research Laboratory Directorates portion of this BAA for SOLIC applications. Demonstrations and assessments should be at least at the brass board prototype level. The focus is to demonstrate the transition of technology for the application of advanced systems and equipment to the U.S. Army, United States Special Operations Command, and other unique missions related to transformation of the U.S. military and the Global War on Terrorism in the following mission areas:

a. Direct Action Support: Development and demonstration of advanced technology supporting small team and transformational combat units (interim brigade, objective force, and future combat systems) combat operations. This includes close quarters combat and fire support (laser target designation, etc.)
b. Intelligence, Surveillance and Reconnaissance Support: Development and demonstration of technology supporting enhanced situational awareness and real-time intelligence for small team and transformational combat units (interim brigade, objective force, future combat systems) and their tactical support elements at forward operating bases and joint special operations task force locations.
c. Special Reconnaissance Support: Development and demonstration of technology supporting dismounted, long term reconnaissance into non-permissive areas.
d. Psychological Operations: Development and demonstration of equipment providing production and dissemination and assessment of Psyop media. This includes leaflets, RF broadcasts, and text messaging and other formats.
e. Expeditionary Warfare/Unconventional Warfare: Development and demonstration of technology and systems supporting rapid deployment operations. This involves the rapid build-up of lethal and sustainable forces in remote areas.
f. Military Operations in Urban Terrain: Development and demonstration of technology and systems supporting a range of military operations in urban terrain. This includes enhanced situational awareness and use of unmanned systems.
g. Network Centric Warfare: Development of technology and systems for engaging enemy network systems, and protecting friendly networks.
h. Knowledge Superiority: Development, application and demonstration of hardware and software to provide and apply knowledge superiority to U.S. Army and Special Operations Forces objectives.
i. Counter-drug Operations: Development and demonstration of technology and systems supporting counter-drug operations. This includes equipment that is able to detect and identify the presence of drugs in any form, or in any container.

Technical Point of Contact: Dr. Keith Aliberti, keith.m.aliberti.civ@mail.mil, (301)394-2320.

3.2.13. Technology Demonstrations and Assessments for Department of Defense Biometrics. The use of biometrics as an enabling technology has grown recently due to its success in various military applications. Biometrics has an important role as an enabling technology in Department of Defense (DoD) mission areas such as intelligence (e.g., tagging, tracking, locating), access control (both physical and logical), and forensics (e.g., latent matching). In addition, biometrics can be leveraged to support various other missions within DoD to include Identity Management.

As biometrics matures within DoD, the requirements and needs of the user are becoming increasingly complex and require specific solutions that have not yet been developed. It is DoD's intent to advance the state-of-the-art in a targeted approach to provide users with new and enhanced biometrics capabilities. The U.S. Army Research Laboratory (ARL), on behalf of the DoD Biometrics Task Force, solicits proposals focused on the development and demonstration of functional models and the assessment of biometric functionality across the two (2) Focus Areas indicated below that can lead to a demonstration in a relevant environment, at the brass board level, within 18 months. Demonstrations and assessments will be performed in coordination

with the DoD Biometrics Task Force. Results are to include technical performance measurements and analysis from actual testbeds and laboratory environments that indicate the effectiveness of the technology to advance the state-of-the art in current biometrics capabilities across and/or within the following two (2) Focus Areas.

a. Single Sensor Capturing Multiple Modalities: The ability to collect biometric data is a critical step in the overall biometric process. Traditional biometric collection systems are able to collect a single biometric (e.g., fingerprint). In some cases, a single device can use multiple sensors to collect multiple modalities (e.g., finger, face, and iris). However, using multiple sensors to capture multiple modalities demands extra time and resources. The ability to capture multiple modalities with the same sensor, whether contact or contactless, would be a valuable asset for our Warfighters and users within DoD. Below are examples of possible multi-modal fusion sensor challenges that could be addressed:
    - Hand Capture – Could collect palm, hand geometry, fingerprint, and/or vascular biometrics with a single sensor
    - Face Capture – Could collect face, ear, and/or iris biometrics with a single sensor
b. Multi-Modal Matching Capability: Several biometric systems rely on the use of a single biometric modality (e.g., fingerprint) for the verification and/or identification of individuals to produce highly accurate results. However, with the advent of stand-off biometric collection and less than optimal samples due to the tactical environment, relying on only a single modality has the potential to limit the matching accuracy. Future biometric technologies must be able to combine multiple modalities (e.g., fingerprint, iris, face, voice, DNA, palm, vascular, ear) of varying quality and origin, and other non-biometric data, without sacrificing speed, to allow for improved matching and more robust identity analysis. Below are examples of possible multi-modal matching algorithm challenges that could be addressed:
    - Algorithms that can adapt their matching capability to the types of biometric modalities available and their respective quality
    - Algorithms that can execute on many processor architectures, from smaller/embedded devices to larger enterprise systems

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3.2.14. Quantitative Technology Assessment. Models to examine the total performance and potential payoff of new and evolving technology on Army vehicles and systems. Tools to assess the real benefits of evolving technologies and provide quantitative basis for strategic research decisions. Research in this area will provide a better, scientific understanding and technical foundation for developing technology solutions for the next generation of capabilities.

a. Methods for including reliability, survivability, manufacturability, integration, etc. in a technology development tradespace.
b. Methods to slice the design space and visualize multidimensional tradeoffs, beyond 2D Pareto front and 3D Pareto surface.

c. Methods to increase confidence that a technology tradespace has been sufficiently bounded and populated.
d. Automatically populating a technology tradespace with input from multiple databases that use differing schemata, hierarchies, and attributes.
e. Visualizing multidimensional tradespaces in manners that enable human-in-the-loop manipulation and control.
f. Predicting subsystem and system-level variances based on uncertainties at the technology component level.
g. Ability to model and assess reliability and cost to provide insight into long-term product reliability and maintainability, for existing capabilities and future technologies.
h. Assessing the sensitivity of design alternatives to changes in design parameters, requirements, and technologies.
i. Removing or reducing the subjectivity associated with weightings on measures of performance and effectiveness, as well as assessing the sensitivity of these stakeholder desires to system capability.
j. For a combination of preferred technologies, modeling and analysis capability to assess the technology tradespace that enables understanding of the magnitude and direction of affected capabilities, compliant requirements, and required funding.

Technical Point of Contact: Mr. Eric Spero, email: eric.spero.civ@mail.mil, 410-278-8743.

3.2.15. Technology Demonstrations and Assessments for Counter Insurgency Operations. The U.S. Army seeks proposals for the research and demonstration of technologies to detect, disrupt, degrade, and dismantle insurgent groups for future conflicts. The Army envisions that in the future, many areas of the world may be plagued by insurgencies which survive in some measure due to problems of poor governance, corruption, militant resistance, ethnic conflicts and criminality. The security problems for the Army are likely to be defined by insurgent groups attacking host nation government forces from within the population and exploiting the host nation government's challenges in providing security and enforcing their laws. These insurgencies are likely to be supported by terrorist groups, criminal groups, and gangs. The objectives of this effort are: researching and demonstrating a comprehensive information management methodology that may include both material (i.e. cyber defense capabilities, human terrain mapping, sensors, etc.) and/or nonmaterial solutions (i.e. doctrine, tactics, procedures, techniques, etc.); and, transitioning this methodology to organizations that have the responsibility of countering insurgent groups.

Technical Point of Contact: Mr. Andrew Ladas, andrew.p.ladas.civ@mail.mil, 301-394-2622.

3.3 Computational Sciences

3.3.1. Simulation-Based Engineering Sciences. Proposals are required in the areas of multi-disciplinary computational sciences research exploiting high performance computers: associated computer science research; and development of leading-edge computing systems to address challenges in simulating practical Army applications. Specific areas of interest include:

a. Innovative and scalable methodologies (including finite element methods, particle methods, meshless methods, etc.) for Computational Mechanics, Computational Fluid Dynamics (CFD), Computational Structural Mechanics (CSM), Computational Electromagnetics and Acoustics (CEA), and Computational Chemistry and Materials (CCM), etc.).
b. Innovative and scalable methods for discrete event simulation (DES) that can be useful to a wide variety of problems within the Army (example: Communications Network Modeling, Scheduling, etc.).
c. Computational methods for interdisciplinary applications (example: structure-medium interaction, Eulerian-Lagrangian, etc.).
d. Multi-scale computational approaches over a wide range of length and time scales (example: Macro-meso-micro approaches, molecular dynamics-continuum mechanics coupled approaches, etc.).
e. Computational methods to address innovative structures for Army applications (designing, manufacturing, testing, verification and validation).
f. Data mining for scientific applications.
g. Large-scale data analytics.
h. Cloud computing and heterogeneous computing architectures.
i. Tactical high-performance computing.
j. Information visualization.

Technical Point of Contact: Mr. Jerry Clarke, e-mail: jerry.a.clarke4.civ@mail.mil, phone: 410-278-9279

3.3.2. Quantum Information Science. Recent advances in Quantum Information Science (QIS) and emerging technologies have opened up the possibilities for achieving improvement in computing, imaging and communications for the Army and DOD. The ARL research program explores improved quantum methods of quantum imaging, quantum computing and quantum communications that can achieve unprecedented resolution, information capacity and security beyond the capability of classical techniques.

Technical Point of Contact: Mr. Ronald E. Meyers, e-mail: ronald.e.meyers6.civ@mail.mil, phone: 310- 394-2111

3.3.3. Signature Management Codes, Predictions and Modeling *. There is an interest in proposals for modeling the effectiveness of signature-reduction applications and proposed applications in the visible, infrared, and radar portions of the EM spectrum and in the acoustic regime for various Army systems, including ground vehicles, aircraft, tactical units, etc.

Technical Point of Contact: Dr. Keith Snail, keith.a.snail.civ@mail.mil, (301)394-5507.
*For additional security information: Mr. Tim Brown, timothy.l.brown24.civ@mail.mil, (301)394-3863.

3.4. Autonomy

3.4.1. Tactical Mobile Robotics. The ARL is interested in basic and applied research in intelligent robotic behaviors that enhance Soldier mission effectiveness. The objectives of this

research are to provide Warfighters with intelligent autonomous aerial and ground mobile robots that remove the Warfighter from harm's way and to provide enhanced situational awareness on the battlefield. This research will lead to the development of intelligent, autonomous systems of robots that will make optimal use of limited resources and will act appropriately in uncertain environments. Research areas of interest include, but are not limited to, advancing the state of the art in the following areas:

a. Localization, world modeling, navigation and exploration.
b. Planning for persistent surveillance.
c. Teaming of autonomous mobile robots with Warfighters.
d. Maintenance of communication under adverse wireless radio channel conditions.
e. Coordination of heterogeneous robots, including air/ground, large/small, tracked/legged, etc.
f. Object detection, classification, recognition, identification and tracking.
g. Learning and adaptation to improve system robustness in real-world environments.
h. Tactically relevant behaviors inspired by concepts of operation of human Warfighters.
i. Self-awareness and introspection for transparency in human-robot collaboration.
j. Multi-robot coordination in any of the above areas of research

Technical point of contact: Mr. Stuart Young, email: stuart.h.young.civ@mail.mil, phone: 301-394-5618.

3.4.2. Microsystems Technology. Robotic platforms extend the warfighter's senses and reach and have been used operationally as sensor, communications, and, in some instances, weapons platforms. Especially in complex terrain, like caves and mountains, or an urban environment, these platforms provide operational capabilities to the warfighter that would otherwise be costly, impossible, or deadly to achieve. Future enhancements to warfighting capabilities require a reduction in platform size and the cohesive operation of multiple platforms.

Consider, for example, a small unit searching a building for potential human threats. The platforms are emplaced or launched initially by the unit or a larger robotic platform but their movement is guided by perceived improvements in situational awareness provided by modifying the platform distribution. Thus, determining waypoints, as well as stable controlled movement between waypoints is critical. The ability to hover or perch is also advantageous to operations.

Similar capabilities are also required when searching caves or demolished buildings, but the terrain is more complex to map and to navigate. Paths are irregular and ground surfaces are no longer smooth. Air flow may be gusty. In caves, especially, the lack of ambient lighting and the thermal uniformity of the environment complicate navigation.

Surveillance of a wide area for perimeter or asset defense is an alternative scenario that requires full autonomy from a collection of microsystems. Not only must the collection provide situational awareness, it must also respond in some manner prior to human intervention. Thus, the requirements on processing to understand and respond appropriately are increased over those of the small unit search.

Enabling the capabilities reflected in the search and surveillance scenarios above requires the solution of fundamental technical issues in several key areas including: aeromechanics and ambulation; electrical power and propulsion; sensing, processing, and communications; navigation and control; mobile, distributed sentience; microdevices and heterogeneous integration of materials; platform packaging; and systems architectures.

Important research issues include:

a. Platform stability and control in high-disturbance environments.
b. Vortex-dominated unsteady aerodynamics of flapping wings at low Reynolds numbers.
c. Bio-inspired, bio-mimetic leg and wing concepts with integrated sensors and actuators.
d. High-force high-bandwidth large-displacement linear actuators.
e. Autonomous and semi-autonomous navigation and control over a network.
f. Group cooperative behavior and planning.
g. Robust and scalable control architectures.
h. Integrated sensing to support mobility, communications, and surveillance.
i. Computational sensing, including compressive imaging.
j. Efficient sensing and information extraction and utilization.
k. Constrained information management within a node.
l. Distributed signal processing, including low complexity techniques for distributed multi-modal sensing and fusion.
m. Dynamic collaborative processing accounting for sporadic sensing and sensor management.
n. Communications and networking, including novel communications modalities, dual sensing and communications and implicit communication.
o. Lightweight robust and possibly asymmetric networking.
p. Integrated cross-layer communications and network design.
q. Techniques for network lifetime extension.
r. Synthesis and development of three-dimensional materials and circuit architectures for sensing, signal processing, and communications.
s. Smart multifunctional materials.
t. Robust, low complexity, low power devices for sensing, signal processing and networked communications.
u. Hybrid power systems.
v. Power harvesting concepts.
w. Power & duty cycle management.
x. Microsystems architectures analysis to understand fundamental limits and perform modeling & simulation.
y. Design tools capable of balancing and optimizing trade-offs in a microsystem architecture.

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3.4.3. Robotics Science and Technology. Fundamental Research is directed towards providing the Army with technological building blocks required to develop future generations of highly capable unmanned systems that will team with Soldiers to successfully conduct multiple missions and activities. Activities fall three distinct areas of robotics that have the potential to significantly impact the future military missions, from the organic intelligence required by the vehicles to autonomously maneuver through complex and dynamic operational environments, to the mechanisms and control schemes that are required to provide the raw mobility to maneuver in three-dimensional environments typical of urban areas or highly dangerous situations such as maneuver through pipes, tunnels, and culverts, to the ability to dexterously manipulate objects of varying size, shape, texture, and weight distribution, to the ability to create numbers of extremely small mobile sensors that can fly through interior spaces or crawl on the ground like insects, providing critical tactical intelligence to our Forces.

To successfully develop such future systems will require the development of key technologies, including:

a. **Adaptive Tactical Reasoning** – The ability to generate tasks to accomplish the mission at hand, reacting appropriately to unforeseen events; to understand teammates, human or otherwise, and what the teammates need to know during the mission, to learn from experience and generalize appropriately from specific examples.
b. **Focused Situational Awareness** – The ability to monitor friendly forces and neutrals and look for threats, to contribute to the general situational awareness of the unit, looking for any salient unexpected events, to continuously predict the future so that anomalies can be more readily detected.
c. **Efficient Proactive Interaction with Humans** – The ability to receive, understand, and acknowledge orders, asking for clarification if needed in a natural fashion utilizing the same odes of command and control that Soldiers use.
d. **Safe, Secure, and Adaptive Movement** – The ability to move on orders or their own initiative from one tactical position to the next with little or no reliance on metric inputs such as GPS..
e. **Interaction with the Physical World** – The ability to pick-up and move objects, either upon semantic direction or their own initiative. And to maneuver in three dimensional terrain, possibly in places that Soldier cannot travel. These capabilities must be applicable to a broad range of scales, from micro-systems through larger tactical vehicles.

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3.5 Atmospheric Sciences

3.5.1 Atmospheric Sensing and Characterization. Improving the measurement of battle space weather variables and the characterization of atmospheric processes through observations applied to critical scientific areas that affect atmospheric, biospheric and hydrospheric modeling, soldier battlefield awareness, survivability, health and tactical decision-making.

a. Develop and apply Army atmospheric observing systems for various applications (such as but not limited to atmospheric processes, bio-warfare threats, chemical warfare threats, battlefield logistics (e.g. soil moisture, flooding), and biometeorology.
b. Development of the methodology, infrastructure, and application of an Army Sensor Simulation Experiment framework to simulate sensor performance in various battlefield environments. This may involve, but is not limited to the following:
    (1) Optimizing sensor designs
    (2) Developing decision support aids for use by various sensors
    (3) Developing optimal simulation modules for sensor performance and distribution. These modules may include, for example, artificial intelligence and state of the art modeling techniques for state of the art computer architectures.
    (4) Conducting trade studies. For example, determining the optimal quantity, distribution, type, frequency of measurement, and accuracy of meteorological sensors for use on the battlefield or other denied geographic regions for the purpose of providing appropriate environmental analyses and forecasts
c. Methodology and applications for the use of satellite remote sensing of boundary layer environmental conditions with emphasis on smaller scales, that is, meso-gamma scale and microscale.
d. Innovative new techniques and novel technology exploitation to retrieve data and extract information on boundary layer weather and atmospheric aerosols from traditional, non-traditional, and non-meteorological sensors and sources.
e. Research on and models of atmospheric effects on sensor imagery under natural and battle-induced conditions.
f. Development of and applications using advanced ultra-compact lidar systems.
g. Atmospheric aerosol properties and behavior, including the natural background, as well as man-made liquid/solid mineral, chemical and biological components.

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3.5.2 Atmospheric Modeling and Decision Aids. Improving the assimilation, analysis, forecasting, and dissemination of real and simulated digitized battle space weather and atmospheric information.

a. Research on and development of models and decision aids for atmospheric effects on radar, lidar, acoustic systems, acoustic and infrasonic acoustic, Electromagnetic (EM), especially electro-optical, and unexplored energy/radiation propagation.
b. Propagation in the battlefield atmospheric environment. This may include, but is not limited to sound detection and ranging techniques, and incorporation of the effects of weather, clutter, and battlefield obscurants into intelligence, surveillance, and reconnaissance.
c. Microscale atmospheric boundary layer meteorology and numerical simulation, at horizontal grid resolutions from 100 to 1 m that address local effects of complex terrain including urban, mountainous and forested areas. .
d. Technology and algorithms for web enabling of numerical weather prediction models, data assimilation methods, and related software including but not limited to web

services, java spaces, widgets, cloud computing, and other emerging methods leading to the efficient distribution and handling of weather forecasting/nowcasting technology on future Army tactical computer platforms.

e. Basic research to characterize and simulate atmospheric mechanical and optical turbulence throughout the boundary layer and over complex terrain including non-isotropy and intermittency, as well as atmospheric modeling and simulation techniques in support of accurate assessment of optical system performance in the Army battlefield conditions.
f. Physically accurate weather visualization tools.
g. Electromagnetic and acoustic propagation, especially for electro-optical system performance, high energy laser effectiveness, emerging THz system design, and infrasonic acoustic propagation analysis, and modeling of polarized electromagnetic propagation measurements through the atmosphere at UV through millimeter-wave lengths under natural and battlefield conditions for mitigating atmospheric effects.
h. Environmental decision support technology (decision support tools) for transforming raw weather information and probabilistic weather forecast model output into mission planning and battle decision intelligence to include the effects decision aids for the use of smoke, camouflage, decoys, and multi-spectral and polarimetric technology
i. Data assimilation methods applicable to numerical weather prediction models at meso-gamma to microscales running with horizontal grid resolution down to less than 10 m, and capable of running in near real time.
j. Data compression methods for large meteorological data bases that can achieve compression ratios significantly greater than current lossless methods and that maintain high accuracies over the entire domain.
k. Innovative technology and methods for detection of severe storms and other atmospheric phenomena such as through detection of impending and current lightning.
l. Tailored applications of meteorology developed for modeling and simulation, transport and dispersion of airborne hazards, real time monitoring, and input data sets for decision aids.

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3.5.3 Intelligent Atmospheric Optics Systems for Army Battlefield Applications. Exploring and developing state-of-the-art innovative technologies for Army Battlefield Applications. The objectives are to mitigate the effects of weather and battle-induced atmospheric processes and constituents; to optimize the performance of friendly forces under realistic battlefield conditions; and to enhance the exploitation of smoke, camouflage, concealment, deception, and multi-spectral and polarimetric technology. For example, atmospheric turbulence introduces random phase distortions and intensity scintillations into the transmitted and received waves. These distortions lead to intensity fading of the received signal in optical communication systems, degradation of image quality in surveillance and automatic target recognition systems, and significant decline in energy density at the target in the high-energy laser based directed energy systems. Combined with an understanding of the impact of atmospheric turbulence effects on

various military systems, develop techniques for mitigation of these effects using intelligent optics elements and systems.

a. Innovative atmospheric sensing, characterization and evaluation techniques including complex-field (phase and intensity) sensors capable of operation in deep turbulence conditions (long-range and slant propagation paths).
b. Research on and models of atmospheric effects on sensor imagery under natural and battle-induced conditions. This area includes active and passive imaging techniques and on-the-fly image processing algorithms that result in dramatic enhancement of image quality in severe atmospheric conditions.
c. Active/adaptive multi-gigabit rates free-space laser communications for high-resolution (high-definition) video information relay.
d. New generation of intelligent (active/adaptive) laser tracking and high-precision beam pointing systems that are resilient to atmospheric effects.
e. Conformal optical systems based on an array of adaptive laser beam transceiver elements for directed energy, remote sensing and laser communication applications.
f. New generation of optical systems for efficient high-energy laser beam projection and relay. That is, develop new optical system architectures and systems that are small size, light weight, less expensive, and more robust in respect to both atmospheric turbulence and platform jitter induced effects.

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3.6 Electronic & Information Warfare Vulnerability

ARL provides survivability, lethality and vulnerability (SLV) analysis and evaluation support over the entire life cycle of major Army systems; and helps acquire systems that will survive and be lethal in an electromagnetic environment. Measurement and emulation of the electromagnetic (EM) spectrum for use in analyzing systems during developmental and operational evaluation would provide insight into system performance and provide an opportunity for mitigating vulnerabilities. These emulators should be mobile thus allowing use in laboratory, anechoic chamber, and field experimentation on communication (including wireless networks), radar, navigation and information systems.

e. CORE COMPETENCY 4: HUMAN SCIENCES

ARL plans, manages, and conducts a comprehensive, multi-disciplinary program of scientific research directed toward defining human performance in sensory, perceptual, cognitive, and physical domains, utilizing experimental and modeling approaches from disciplines such as psychology, cognitive and computer science, neuroscience, human factors engineering, and systems engineering. ARL research provides the scientific foundations for application to militarily relevant domains such as human systems integration, task performance modeling, and anthropometric biomechanical modeling. The end goal is to guide optimal design of human-system interaction in operational environments. ARL also conducts research associated with training technologies, and advanced distributed simulation, including adaptive and intelligent

training technologies, virtual human research, immersive learning, synthetic environments, and training application domains such as medical, dismounted Soldiers, and embedded/live training.

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4.1 Soldier Performance

4.1.1. Soldier Performance Research: Proposals are requested involving Soldier-oriented research and development (R&D) that advances and improves human factors design principles and guidance for enhancing Soldier and small team sensory (e.g., auditory, visual, and tactile), perceptual, cognitive, and physical performance while providing the materiel development community with the information necessary for effectively designing systems that are best suited to the operator, maintainer, or trainer. Proposals for technology for collecting sensory, cognitive and physical performance data (including biomechanics data) in field environments are also requested. Results of studies will be used to quantify trade-offs between the benefits of providing new technology and the cost to the dismounted Soldier of having and using that technology.

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4.1.2. Neuroergonomics: ARL is seeking proposals that provide fundamental research underlying the development of neurotechnologies to enhance human-system interactions. Specifically, ARL is seeking to understand the nature of the human-system interactions and use that information combined with technological advancements across computational and system design fields to create enhanced and total novel interaction technologies for tomorrow's Soldier. This effort requires the translation of laboratory-based neuroscience research and methods to militarily-relevant environments in order to enable system designs that exploit the capabilities of both Soldier's brain function and systems to maximize Soldier-system performance. Research is focused on the capability to sense, process, and extract critical information about brain activity in dynamic, complex environments; characterizing and modeling neural processes in real-world contexts and those processes critical to Army-relevant operational tasks; and creating and extending novel brain-computer interaction technologies which have the potential to revolutionize the basic interactions Soldiers have with their systems and each other. This effort addresses the rapid technological advances in areas such as sensing, computation, robotics, microelectronics, and computer and network information systems that are outstripping the capabilities of the human brain and limiting both Soldier-system effectiveness and the Army's ability to fully exploit investments in these new technologies.
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4.1.3. Social/Cognitive Network Science: This research topic is aligned with the broader ARL efforts in Network Science that also include the domains of Information and Communication Networks and draws on cognitive science, computer science, and social network innovations. ARL's efforts focus on two areas: socio-technical network operations and network-enabled cognition with both areas sharing the goal of the improving cognitive performance for collaboration and decision making in complex network-enabled operations. The research

contributes to the development of theory, measures, models, and understanding of social networks and the cognitive implications of those networks and ultimately will guide the design of human-team-system interaction aligned with future operational systems. Research is conducted via computational modeling, networked laboratory (human-in-the-loop) experimentation, virtual simulations, and field exercises, such as those conducted by the Mission Command Center of Excellence (CoE) and Communications-Electronics Research, Development and Engineering Center (CERDEC). An applied cognitive system engineering approach is used employing cognitive work analysis and the newly developed dynamic social network tools. Key themes include social/cognitive network properties, domain modeling and workflow, networked information requirements, trust in automation, , measurement of team performance, cognitive workload, and situation awareness, and methods to drive the information and communication networks with dynamic social network information for real time support for the Soldier/decision maker.

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4.2 Simulation and Training

4.2.1. Adaptive and Intelligent Training Technologies: Proposals are requested to design, develop, apply, and evaluate artificially-intelligent agent technologies (e.g., computer-based tutors, virtual humans, process agents and authoring tools/methods) to enhance training effectiveness and reduce associated training support costs. The goal of this research is to enhance the realism, adaptability and decision-making skills of artificially-intelligent computer-based tutors and virtual humans to support one-to-one and one-to-many training experiences where human support is limited, impractical, or completely unavailable. Technical challenges include the development/application of intelligent agents that can adapt in complex, ill-defined domains; understanding natural language in multi-sided conversations with trainees; rapid authoring of effective computer-based tutors for individuals and teams, and realistic virtual humans. Anticipated capabilities include computer-based tutors on par or better than expert human tutors and realistic virtual humans that are so visually and cognitively realistic that they are indistinguishable from humans. These capabilities will serve to provide enhanced "self-directed" learning while at the same time reducing associated training support costs.

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4.3 Human Systems Integration

4.3.1 Human Systems Integration Research (HSI): Proposals are sought to optimize total system performance, minimize total ownership costs, and ensure the system is built to accommodate the characteristics of the user population that will operate, maintain, and support it. The purpose of ARL's HSI program is to develop human performance modeling tools and analyses to represent system level mental and physical human performance tradeoffs at the system of systems level as a function of such factors as task requirements, level of automation, interface modality, workload, and type of training. A new dimension to be incorporated is the impact of social and cultural influences. These tools and analyses will support consideration of manpower

requirements, workload, and skill demands collectively and systematically, avoiding information and physical task overload and taking maximum advantage of aptitudes, individual and collective training, and numbers of Soldiers for an affordable Future Force.

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4.3.2 Human Robotic Interaction (HRI): Proposals are requested to develop human factors technologies and design principles that enhance the Soldier interface with robots, and therefore, manage workload, engender trust, and improve overall Soldier-robot performance. As robotic systems increase in capability and functionality, the operator will require "matching" enhancements to the methods and interfaces used to task and control those robotic systems. This includes the investigation of supervisory control, levels of robotic autonomy and interface automation, multimodal inputs and scalable interface technologies, and human-robot and robot-robot teaming that invokes the concepts of trust and social/cultural interactions. Concept validation employs modeling, laboratory and field experiments, and simulations, moving from highly controlled to militarily-relevant environments. HRI also includes research to leverage bio- and cognition-inspired designs for robots to enhance the interaction with Soldiers. Key deliverables are being transitioned to current programs of record as well as to advanced development.

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f. CORE COMPETENCY 5: SURVIVABILITY, LETHALITY, AND VULNERABILITY ANALYSIS AND ASSESSMENT

5.1 Ballistic Vulnerability Analysis and Assessment

5.1.1. Vulnerability Analysis for Under-body Blast. Conduct applied research and advanced development to create enhanced capabilities for assessing the vulnerability of soldiers to the effects of under-body blast. Areas of interest include instrumentation, sensors, data acquisition systems, anthropomorphic test devices, anthropometry, filtering and signal analysis, human response and injury criteria (including experimentation with biological tissue), and modeling and simulation.

ARL is interested in methodologies and models for assessing soldier/platform occupant injury probabilities as well as data collection and analysis in support of the WIAMan program, which is developing a new military-specific anthropomorphic test device and associated injury assessment tools for use in live-fire test and evaluation and vehicle development efforts.

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5.2 Electronic & Information Warfare Vulnerability Analysis and Assessment

5.2.1. Radio Frequency Directed Energy (RFDE)/ High Power Microwave (HPM)/Electromagnetic Effects/ Electromagnetic coupling phenomena/ Electromagnetic Energy Survivability. ARL provides survivability, lethality and vulnerability (SLV) analysis and evaluation support over the entire life cycle of major Army systems; and helps acquire systems that will survive and be lethal in all environments against the full spectrum of battlefield threats. This is done by conducting SLV investigations, experiments, simulations, and analyses. ARL develops tools, techniques, and methodologies to improve the SLV analyses. ARL has a continuing interest in a broad spectrum of research in these areas, including: electromagnetic (EM) coupling phenomenology and antenna measurements.

There is ongoing interest in EM coupling to analog and digital systems, subsystems, components, boards, integrated circuits (ICs), and components. Of interest are susceptibility levels and dependent parameters. Understanding coupling phenomena provides insight into the system effects and is useful for analyst projections. Additionally, a methodology (that can be validated in a laboratory or open air environment) is needed to analyze and understand the performance of communication/electronic/ADP equipment when deployed/operating in battlefield electromagnetic environments (EME). EME sources in the battlefield include radars dedicated to various warning functions (acquisition, track, etc.) covering broad frequency bands, communication transmitters, and accouterments of EM generating equipment used in the battle management/command, control, communications, computers, and intelligence (BM/C4I) functions during a battle. Some of the sources encountered in the battlefield come under the realm of high-power microwave (HPM) and the coupling phenomenon associated with the pulsed environment need to be understood.

Ideally a HPM predictive tool would be developed and used for electronic equipment survivability assessments. The radio frequency (RF) coupling study can be approached by placing the equipment under test (EUT) and the ancillary equipment in an anechoic chamber:

a. To understand the low level RF coupling phenomenon associated with narrow-pulsed and/or transient EM environment.
b. To characterize its performance when exposed to out-of–band environment in the 100 MHz to 18 GHz and around 35 and 95 GHz range.
c. To diagnose/instrument digital EUT systems; e.g., computers, network devices, receivers, circuits, for RF effects. These measurements are conducted in an anechoic chamber to insure clutter free environment and facilitate cause and affect relationships observed due to RF environment.
d. To understand complex antennas and the interaction with the ground and other clutter.

The results from out-of-band radiated susceptibility measurements would be invaluable in characterizing EUT susceptibility profiles. This profile would define EUT system sensitive frequencies and the corresponding incident energy levels required to induce an electronic effect. System response against narrow-pulsed or EM transient pulsed environments would allow an analyst to project the performance behavior of the system in a tactical environment. If performed

thoroughly, this effort may provide insight into predictive tools for the system performance in the presence of high-power microwave/directed energy weapons (HPM/DEW).

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5.2.2. RF Digital Models/Simulations. Developing theoretically based digital models and simulation tools for the analysis of RF electronic countermeasures (ECM) against radar/sensor functions. These tools would be mathematically defined in order to verify functionality. The tools would identify/quantify the information gained or lost by the radar's receiving/signal processing function and guidance function of the radar/sensor system. New techniques for modeling and simulation of radar functions and their interaction with the external environment, specifically ECM, are also being sought.

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2. ARMY RESEARCH OFFICE (ARO)

a. RESEARCH AREA 1: MECHANICAL SCIENCES

1.0 Mechanical Sciences. Research supported in the Mechanical Sciences Division of the ARO is concerned with a broad spectrum of fundamental investigations in the disciplines of fluid dynamics, solid mechanics, complex dynamics and systems, and propulsion and energetics. Though many creative and imaginative studies concentrate on a particular sub-discipline, increasingly, new contributions arise from interdisciplinary approaches such as the coupling between aerodynamics and structures, complex dynamics and systems, combustion and fluid dynamics, or solid mechanics and structures as in the structural reliability areas. Additionally, several common themes run through much of these four sub-disciplines, for example, active controls and computational mechanics. Research in such areas is addressed within the context of the application rather than as a separate subject of study. Fluid dynamics research is primarily concerned with investigations in the areas of rotorcraft wakes, unsteady aerodynamics of dynamic stall and unsteady separation, and fundamental studies of micro adaptive flow control. Solid mechanics include a wide array of research areas such as high strain rate phenomena, penetration mechanics, heterogeneous material behavior, and reliability of structures. The complex dynamics and systems area is focused on investigations in vehicle structural dynamics, and simulation and air vehicle dynamics including rotor aeromechanics. Research in the propulsion and energetics area is concentrated on processes characteristic of reciprocating (diesel) and gas turbine engines and the combustion dynamics of propellants used for gun and missile propulsion. The following narratives describe the details of the scope and emphasis in each of these sub disciplinary areas.

1.1 Fluid Dynamics. Research in fluid dynamics supports the development of improved or new technology for advanced helicopters, small gas turbine engines, improved airdrop (parachute) systems, maneuverable high-speed missiles, high performance gun-launched projectiles, and miniature unmanned air vehicles. While basic research studies that address the fundamental flow physics underlying these devices are solicited, innovative research in the specific topical thrust areas listed below is especially encouraged.

1.1.1 Vortex-Dominated Flows. In contrast to fixed-wing aircraft, rotorcrafts always operate under the influence of their own wakes. The prediction of rotor performance, vibratory loads, and the associated noise due to blade-vortex interaction depend strongly on the accurate prediction of the rotor wake. However, the prediction methodology of this wake remains one of the major challenges in fluid mechanics. Current computational fluid dynamics (CFD) approaches are computationally intensive, especially for Eulerian methodologies where the vorticity diffuses numerically through the grid points and makes predication inaccurate. The process by which vorticity is shed by the blade, and its eventual roll-up to form vortex filaments are not now adequately simulated. In fact, under certain flight conditions and due to negative lift, multiple vortices are observed to form over the blade tip. The application of non-intrusive optical diagnostic techniques should yield new phenomenological understanding for the study of multiple vortices, the wake structure, and its development. New numerical algorithms or different techniques to increase accuracy and reduce the computational requirements are required.

1.1.2 Unsteady Aerodynamics. The flow fields around many modern Army weapons systems are characterized by a high level of unsteady flow, which can neither be predicted adequately by steady nor quasi-steady approaches. One classical example of unsteady aerodynamics of very high Army relevance occurs on the retreating blade of a helicopter rotor blade. At high angles of attack the retreating blade of the helicopter experiences boundary-layer separation that leads to load and pitching-moment overshoots. While mild separation causes increased vibration and reduces system performance, severe dynamic stall leads to unacceptably large vibratory loads, severe limitation to forward flight speed, and diminished maneuver capabilities. The physics of this unsteady flow phenomenon are known to depend on the Mach and Reynolds numbers of the flow, and hence future research in this area needs to be performed under realistic flight conditions. In addition, improved theoretical and numerical simulation is needed for the understanding of the unsteady separation process, and for the evaluation of concepts that may lead to greater flow separation control. Flow field simulations must be capable of accounting for boundary layer transition, and under some circumstances, the transition of the separating free shear layer. To achieve a fundamental understanding of the separation process, detailed experimental measurements of velocity and pressure in the separating region and the development of new turbulence models that are valid during dynamic stall are needed. In this regard, the validation of numerical simulations must focus on quantitative flow field measurements rather than the mere quantitative measurements on the airfoil surface. In addition, the flow field measurements require the use of new non-intrusive optical methods. Combined experimental and numerical efforts towards the control of unsteady separation using passive and active flow control, including the emerging field of Micro-adaptive Flow Control, are also sought.

A second example of the importance of unsteady aerodynamics to the Army occurs during the maneuvering of missiles and projectiles. As future emphasis in flight vehicle control and "smart" systems pervades munitions design, greater understandings of unsteady aerodynamic phenomena, such as; high alpha dynamic separation, vortex shedding, control surface/vortex interaction, divert thruster/vehicle interaction, roll control stability and propulsion system integration, will be required. It is anticipated that new composite material vehicles will have stringent thermodynamic limits and enhanced nonlinear aero elastic response to maneuver forces. Smart structures and MEMS technology will redefine control strategies, control surface shape and control surface dynamics, consequently driving fluid dynamics into new areas of research. All of these developments will require the prediction and experimental verification of complex nonlinear transient flow fields. In turn, these developments will require improved CFD for turbulent flow separation prediction, large eddy simulation, vehicle vortex interactions, and the accurate computations of gross flow field response to MEMS boundary layer flow perturbations. Parallel developments in experimental techniques will also be required to measure these complex flow fields in efforts to verify and guide the predictive technology.

1.1.3 Micro Adaptive Flow Control. Micro Adaptive Flow Control (MAFC) technologies enable the control of large-scale aerodynamic flows using small-scale actuators. MAFC technologies combine adaptive control strategies with advanced actuator concepts; such as, micro-scale synthetic jets, microelectromechanical systems (MEMS)-based microactuators, pulsed-blowing, plasma actuators, and combustion actuators. MAFC techniques are used to cause the delay, or

prevention, of fluid flow separation; to induce flow separation in previously unseparated flow; to alter supersonic flow shock structure; or to otherwise alter the large-scale flow field and provide overall system benefit. Army systems for which MAFC is currently being investigated include on-blade controls, dynamic stall control on helicopter rotor blades, separation control for drag and buffet reduction on helicopters, surge and stall control within Army gas turbines, and dispersion reduction and terminal guidance of subsonic, transonic, supersonic and future hypersonic Army projectiles.

Even though many successful demonstrations of the efficacy of MAFC technology have taken place, much of the supporting research has tended to be somewhat Edisonian in nature. To enhance and focus the adoption of MAFC technology into Army weapon systems, basic research is needed. MAFC research is needed but not limited to the following areas: the development of fundamental understandings of the methods by which MAFC actuation alters the overall flow field; the development of phenomenological models for flows and surface forces in micro and nano channels; the development of robust and efficient MAFC actuators leading to greater control authority and higher bandwidth; the development of computational analysis methodologies capable of accurately and efficiently predicting the effect of unsteady MAFC actuation on the entire flow field; and the development of methods to integrate all these technologies into Army systems.

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1.2 Solid Mechanics. Solid mechanics research plays a crucial role in the prediction of strength, damage initiation and failure progression of Army material systems under extreme loading conditions, such as blast, shock, impact, penetration, and thermal cycling. This research topic addresses the need to understand the response of Army assets to high rate impact and explosive detonation. It integrates approaches based on finite deformation, high pressure and high strain-rate, damage, and failure mechanics. Innovative use of material combinations for specific applications necessitates understanding the behavior of military systems under complex and severe constraints. The program seeks to develop an understanding of the underlying physics of solids that form the foundation of optimization tools to enhance performance, and minimize weight and volume for the future design of Army and DoD systems. Research approaches should consider the topological effects (both micro- and macro-scale), specific material geometry, layering, and interface properties on response to high rate loading. In addition, solid mechanics approaches may address non-traditional concepts including biologically inspired hierarchical structures, soft materials, human tissue and functional degradation of electronic components. Research should be conducted through a combination of physically based experiments, analysis, and computations to address these difficult multi-physics problems. Predictive models, validated by well-characterized experiments, are needed to identify dominant failure mechanisms at relevant scales. An important aspect of this research area is the deformation and fracture of materials under high strain rates ($>10^7$ s^{-1}), strains (ranging from 2% up to 100%), high temperatures (up to the melting point), and high pressures (up to 5 GPa). An important aspect of solid mechanics research is the development of novel techniques to expand the design space of new hierarchical design principles for the purpose of creating microstructures that eliminate traditional inverse material property relationships to enable a combination of

disparate properties (i.e. strength and toughness, strength and density, hardness and ductility, etc...).

1.2.1 Mechanics of Heterogeneous Systems. The mechanics of structures involves the development of integrated analytical, computational, and experimental approaches to investigate rate dependent behavior of heterogeneous materials that may include combinations of high strength and lightweight functionally graded material systems. Experimental and computational techniques are needed to optimize material microstructure as well as the topology of systems to provide the desired structural response for specific boundary and loading conditions. Of special interest is the thermo-mechanical response at strain rates encountered in high-speed impact or explosive loading. Phenomena of interest are wave propagation, scattering, dispersion, and progressive failure behavior.

Quantitative prediction and measurement of parameters related to dominant heterogeneities and mechanisms are needed at appropriate length and time scales for specific material systems in order to relate atomistic and micro effects to the macro scale. Deterministic and statistical scaling methodologies are needed for toughness, strength, and geometrical effects which account for heterogeneities such as interfaces, interphases, reinforcement distribution and their combined effects on failure. Constitutive relations for multi-scale mechanisms should include mechanism-based and experimentally verifiable failure and damage criteria to investigate hierarchical structures for blast- and ballistic-impact mitigation. The integration of sensor technology and the concept of adaptive microstructures may be explored for enhanced control of energy dissipation and load transfer under multiple loading conditions.

1.2.2 Mechanics of Soft Materials & Biologic Systems. The mechanics of biologic structures involves the development and validation of a hierarchical approach to accurately predict stresses, strains, and cavitation in biologic tissue resulting from blast shock waves and high rate blunt trauma. The development of improved protection and injury prevention for military specific injuries requires experimental techniques capable of characterizing the response of soft materials in compression, tension, or shear for strain rates that range from 10^2 to10^5 s^{-1}. High rate loading of different durations and amplitudes may lead to cascading events that cause functional loss and impairment of human tissues. Identification of resultant fundamental processes ranging from molecular changes to physical injury is in their infancy for high rate loading conditions. Such identification will lead to the quantification of high fidelity injury thresholds and novel protective solutions. Several aspects of tissue damage are of interest: (a) high strain rate characterization of constitutive behavior of damaged tissues, (b) damage initiation and evolution at the cellular level, (c) force transduction through temporal and spatial scales from organs to cellular substructures, and (d) effect of blast load (pressure and electromagnetic loads, toxicity, etc.) on short and long term functionality of lower extremities. The aforementioned issues must be placed in perspective of high rate loads and their transmission through protective equipment, human tissue and bone. Advances require interdisciplinary teams combining solid mechanics and biological sciences.

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1.3 Complex Dynamics and Systems. Modern research concerning the dynamics of complex and innovative engineering systems to enable unprecedented Army operational capabilities requires a highly interdisciplinary approach spanning many aspects of engineering, mathematics, complexity science, and physics as well as the dynamics of biological structures and systems. Numerous research needs of Army interest are driven by cooperative, complementary, stochastic, and sometimes conflicting interactions amongst interconnected dynamics and field phenomena ranging from thermal fluctuations in nanosystems to nonlinear aeroacoustic induced vibrations to efficient and sustainable energy flows in interdependent systems. Consequently, the Complex Dynamics and Systems program encompasses a broad research spectrum and seeks to cultivate a cadre of avant-garde engineers, mathematicians, and scientists capable of skillfully transcending traditional disciplinary bounds to generate leap-ahead fundamental understanding and pivotal innovation across the full range of length scales concerning the underlying physics, information flow, mathematical modeling, and control of isolated or interdependent dynamical systems. Further information on the programmatic thrust areas of greatest interest are detailed in the paragraphs that follow.

1.3.1 Nonlinear Dynamics, Force Generation, and Field Interactions. Nonlinear dynamics is a rich research endeavor of direct impact on a multitude of Army systems from nano/microsystems to conventional rotorcraft aeromechanics. Research in this thrust focuses on novel mathematical, numerical, and reduced order modeling methods, fundamental physical understanding, and exploitation of structural, multi-body and multi-physics dynamical systems whose state transition and control parameter behavior are necessarily characterized by either strong, smooth, or non-smooth nonlinearities; holonomic and nonholonomic constraints; stochastic dynamics; or high-dimensional interactions with granular media and field phenomena. Novel methods for reduced order modeling and exploiting these complex behaviors and interactions for superior performance are especially sought. Research topics of interest are diverse and some examples include (but are not limited to): non-Lyapunov based stability theory of nonlinear systems; nonlinear inverse problems and system identification; geometric mechanics; chaotic and stochastic transitions; symmetry; integrability and stability of nonholonomic systems; nonlinear aeroelasticity and wake/vortex/acoustic-field induced structural oscillations; de-stabilizing time-delays; bio-dynamics; wave phenomena, multi-body, and structural interactions within granular media of varying viscosity; nano- to macro-scale continuum field interactions (thermal, fluid, electromagnetic, photomechanical, viscoelastic); chaos, instabilities, bifurcations, chimera states, and synchronization of coupled nonlinear oscillators; solitons; high-frequency oscillations; nonlinear, impact, blast, and stochastic excitations of nonlinear systems; opportunistic exploitation of nonlinearities and unique physical interactions in NEMS/MEMS; nonlinear dynamics of multi-body hybrid translational/rotary systems with nonlinear/non-smooth connections; intelligent force perception, interpretation, and action in compliant environments; nonlinear physics of dissipation, slipping, and damping; or tightly coupled unsteady aeroelastic-rigid body dynamics. Inspiration from nature's solutions to problems relevant to micro-vehicle dynamics and robotics is of value, however, understanding how competing factors in biology lead to sub-optimal solutions that modern engineering science can overcome may lead to truly innovative solutions.

1.3.2 Multi-Dimensional and Dissipative Dynamical Systems. This thrust focuses on the mathematically rigorous methods and physics of continuous and discrete high-dimensional

dynamical systems; the engineering science of complexity; renormalization, projection-operator, and uncertainty propagation methods in spatiotemporally heterogeneous dynamical systems; and development of a formalism for systems synthesis. Novel methods for the engineering analysis of high-dimensional linear, nonlinear, and stochastic dynamical systems is sought to include model order reduction, stability, bifurcations, attractors, uncertainty propagation, statistical fields, etc. In large-scale networks of interdependent dynamical systems, temporal anisotropy, spatial non-locality, and multiscale processes precipitate local dynamics to global responses in a non-straightforward manner such that ergodicity may only apply at certain spatiotemporal scales and hierarchies. Fundamental investigations are required to develop the abstract formalisms and frameworks guiding the scaling analysis, causality, energy and multidimensional information flow, hierarchal, adaptive dynamics, multi-objective synthesis, and new mathematical performance metrics of increasingly complex and dissipative (non-equilibrium) systems comprised of distributed, interdependent, and heterogeneous subsystems. The engineering science of complexity constitutes an effort to leverage the unprecedented insight from complex systems science regarding a wide variety of biological, economic, and social systems. While discovery and understanding of complex systems in nature, economics, and society are of profound value and impact, our ability to exploit this knowledge to engineer the controllability, fragility, propensity for self-organization, and/or robustness of interdependent dynamical systems will demonstrate true mastery. Of particular interest are methods and techniques from complexity science, dynamical systems theory, non-equilibrium physics, differential topology, graph theory, stochastic calculus, percolation theory, and associated stability and control principles. Multiscale projection-operator methods and renormalization groups for novel reduced order modeling strategies for complex dynamical systems is of major interest. Within the context of the aforementioned theoretical approaches, characterization of the uncertainty propagation and non-Gaussian stochastic dynamics is of paramount significance. Determining, understanding, and manipulating the emergent behaviors, persistent or transient mathematical structures, self-similarity, chaotic and fractional dynamics, etc, will lead to unprecedented capabilities of complex engineered systems and high dimensional multi-scale simulation. Furthermore, research developing the formalism for systems synthesis and systems-level stochastic nonlinear inverse problem analysis is sought after, where deep understanding of the nonlinear and stochastic dynamics of complex systems drives optimal system modeling. The theoretical framework for determining the efficient allocation of computational resources or component characteristics for the optimum desired systems-level dynamics remains an open challenge and the intricate dynamics of multi-dimensional and complex systems bring about a wealth of challenges in this endeavor.

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1.4 Propulsion and Energetics. Propulsion and Energetics Research supports the Army's need for higher performance propulsion systems. Future systems must provide reduced logistics burden (lower fuel/propellant usage) and longer life than today's systems. Fundamental to this area are the extraction of stored chemical energy and the conversion of that energy into useful work for vehicle and projectile propulsion. In view of the high temperature and pressure environments encountered in these combustion systems, it is important to advance current understanding of fundamental processes as well as to advance the ability to make accurate, detailed measurements

for the understanding of the dominant physical processes and the validation of predictive models. Thus, research in this area is characterized by a focus on high pressure, high temperature combustion processes and on the peculiarities of combustion behavior in systems of Army interest.

1.4.1 Engines. Research on combustion phenomena relevant to engines is focused on intermittent reacting flows encountered in diesel combustion chambers and on continuous combustion characteristics of small, gas turbine combustors. Optimizing engine performance, through understanding and control of in-cylinder combustion dynamics, while retaining high power density, is a major objective. This focus leads to a strong emphasis on fuel injection processes, jet break-up, atomization and spray dynamics, ignition, and subsequent heterogeneous flame propagation. Research on heterogeneous flames requires supporting study into kinetic and fluid dynamic models, turbulent flame structure, soot formation and destruction, flame extinction, surface reactions, multiphase heat transfer, and other factors that are critical to an understanding of engine performance and efficiency. An additional consideration is the high pressure/temperature environment encountered in advanced engines, which influences liquid behavior and combustion processes at near-critical and super-critical conditions. Of particular interest are investigations of fundamental characteristics related to highly stressed engines, such as elevated temperature and pressure combustion, accelerated mixing, and transient heat transfer. Engine performance degradation under low temperature conditions due to reduced fuel volatility, high oil viscosity, poor atomization and vaporization, etc., is a major concern. Fundamental research is needed in many areas, including low temperature physical and chemical rate processes, instantaneous friction and wear mechanisms, and combustion instability effects at low temperatures. New characterization methods to investigate kinetics and flame phenomena at high pressure are needed. New computational methods to be able to model complex reacting systems are also needed. With advances in sensing, modeling, and control architectures, it is becoming possible to further optimize the performance of combustion systems. Providing the foundations for such active control is also a major goal of the program.

1.4.2 Propellant Combustion Processes. Research on propellant combustion processes is focused on understanding the dynamics of the planned and inadvertent ignition and subsequent combustion of energetic materials used for propulsion in gun and missile systems and in ordinance. The program is also addressing the characterization of advanced energetic materials, e.g., those based on nanoscale structures and/or ingredients. Basic research is needed in several areas, including: thermal pyrolysis of basic ingredients and solid propellants; flame spreading over unburned surfaces (particularly in narrow channels); surface reaction zone structure of burning propellants; chemical kinetics and burning mechanisms; propellant flame structures; characterization of physical and chemical properties of propellants and their pyrolysis products; and coupling effects among the ignition, combustion, and mechanical deformation/fracture processes. The use of advanced combustion diagnostic techniques for reaction front measurements, flame structure characterization, and determination of reaction mechanisms is highly encouraged. Especially of interest are novel methods which can well characterize the ignition and burning behavior of a material utilizing only minute quantities of that material. Complementary model development and numerical solution of these same ignition and combustion processes are also essential. There is also need to understand the unplanned or accidental ignition of energetic materials due to stimuli such as electrostatic discharge, impact,

friction, etc. This requires, for example, research on the processes of energy absorption and energy partitioning in the materials, the effect of mechanical damage on the ignition events, and other topics relating to the safety of energetic materials.

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b. RESEARCH AREA 2: ENVIRONMENTAL SCIENCES

2.0 Environmental Sciences. The Environmental Sciences Division of the ARO supports fundamental research in the Atmospheric and Terrestrial Sciences, i.e. research in the physical sciences of planet Earth in support of Army requirements. The need for research in the environmental sciences stems from the impact that the environment has upon virtually all aspects of Army activities. To function properly and efficiently in all environments, the Army requires comprehensive knowledge of the environment and the environment's impact on operations.

The Army is also committed to be a national leader in environmental and natural resource stewardship for the present and future generations as an integral part of its mission. Responsibilities in this arena include the restoration of sites contaminated through prior Army activities, as well as achieving a state of environmentally sustainable operations on all military installations, particularly those utilized for training and testing. Cost-effective land use and restoration requires in-depth knowledge and understanding of the physical principles and processes operating in the terrestrial and atmospheric science.

The environment is a multifaceted and dynamic system so that there is an increasing need for multidisciplinary approaches to address the complex research issues that presently characterize the atmospheric and terrestrial sciences. Because of limited resources, not all subjects that fall within the broad interest areas defined below can be included in the current ARO Environmental Sciences research program at any point in time. Emphasis areas are reviewed periodically and funding concentrated in specific areas on a 3-5 year time frame.

2.1 Terrestrial Sciences. Primary emphasis is directed toward understanding the behavior of the land surface and the near-surface environment, understanding the natural processes operating upon and within these domains, and modeling these environments for predictive and simulation purposes. Special emphasis is given to the need to better understand, model/simulate, and predict those environments/conditions that are most extreme, dynamic, or restrictive to systems performance or military operations. The three areas of current interest to the Terrestrial Sciences program are:

2.1.1 Terrain Properties and Characterization. Characterizing terrain features and conditions from sparse data plus the accurate detection of short-term dynamic surface conditions and terrain feature change are high priority research issues. A problem of particular importance is the accurate remote sensing measurement of soil moisture at the scales of Army operations (e.g. 10^2-10^3m). Knowledge of the properties and phenomenology of the surface and near-subsurface is critical to supporting military operations on land, ranging from operational mobility, the detection of landmines and unexploded ordinance, natural material penetration/excavation,

military engineering activities, to training and testing land sustainability. New approaches are also sought for non-intrusive geophysical characterization of subsurface materials and their spatial distribution; the prediction of location, frequency, and scale of subsurface heterogeneity; the detection and discrimination of buried objects (particularly landmines, unexploded ordinance, hazardous wastes, and contaminant plumes), tunnels and underground structures; and high-resolution field data sets for non-intrusive measurement validation. Finally, the basic research leading to the ability to discriminate subsurface features and objects in the presence of surface roughness, natural geologic heterogeneity, and anthropogenic clutter is encouraged.

2.1.2 Terrestrial Processes and Landscape Dynamics. In particular, there is a need for the development of first-principle physical/chemical process models and computer-based techniques for monitoring, modeling, and simulating the natural environment, as well as improved technologies and methodologies for environmental characterization and prediction. Special emphasis is given to the need to better understand, model/simulate, and predict those environments/conditions that are most dynamic or restrictive to systems performance or military operations. The development of an improved understanding, physical representation, and quantification of terrestrial processes affecting Army operations are of particular interest to this research area. Improved measurements and theoretical treatments are needed to treat the complex, often nonlinear dynamics governing these processes, which are a result of both physical and biologic processes and the interaction of these processes with terrain evolution.

2.1.3 Terrestrial System Modeling and Model Integration. Geospatial modeling encompasses the application of geospatial technologies to basic science questions of Army importance and concentrates on increasing knowledge about the interaction of terrain, weather, human culture and infrastructure, and their combined effects on military operations. The primary research goal within this area is to advance the theory, methods, and models for geographic analysis. This goal requires advances in human understanding of spatial conditions within their operational environment, improved human and machine learning and reasoning, and exploration of new conceptual spatial models for representing significant aspects of the natural, cultural, and infrastructure environment, and/or advances in visualization. Also of interest is the cognitive understanding and utilization of geospatial information, analysis, representation, and modeling of multiple types of geospatial data, and knowledge discovery from spatio-temporally referenced data.

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2.2 Atmospheric Sciences. The Army has the responsibility to provide fundamental knowledge of the atmospheric boundary layer over land to the U.S. armed services. Intelligence preparation of the battlefield depends on a full knowledge of atmospheric conditions and their effects on operations, weapon systems, and the soldier. It requires an ability to estimate atmospheric details at specific locations and at present and future times to maximize strategic weather advantages. Knowledge of the atmosphere and its effects on soldiers and sensor systems are essential for command and control as well as visualization of the battlefield at all echelons. The Army lead responsibility for chemical and biological defense requires detailed knowledge of chemical and biological aerosol threats. In garrison, Army training and preparedness depend on

accurate representation of atmospheric test conditions and on physically correct portrayal of atmospheric processes and effects in simulations.

The research program is broadly based to address the wide spectrum of conditions and influences of the atmospheric boundary layer on Army operations and systems. It is divided into three general research areas of the boundary layer problems: atmospheric effects on sensors and systems, characterization of the atmosphere at high resolution, and management of atmospheric information.

2.2.1 Atmospheric Effects on Sensors and Systems. The Army depends heavily on propagation of electromagnetic and acoustic signals through the atmosphere for detection, ranging and operation of smart munitions, as well as reconnaissance and information dominance of the battlefield. Atmospheric properties, like turbulence and aerosol loadings, can severely impact the performance of optical and infrared sensors as well as acoustic detection systems by affecting the propagation, imaging, and coherence of the received signals from active or passive systems. Furthermore the effects of surface and natural environmental conditions on propagation of images and signals must be considered because of the near-ground operation of many Army systems. Research topics cover a wide range of topics related to energy propagation, including novel imaging techniques and reconstruction, aerosol obscuration and detection and acoustic propagation and location.

2.2.2 Characterization of the Atmosphere at High Resolution. The Army requires knowledge of the physical processes in the atmospheric boundary layer at the engagement scale of the battlefield. This region is the most inhomogeneous and changeable portion of the atmosphere. Comprehensive characterization of wind velocity, temperature, moisture, surface energy exchanges and fluxes at resolutions showing their scales of variability in the atmospheric boundary layer are essential for advancing understanding of boundary layer processes affecting Army operations and systems. Research topics span a full spectrum of atmospheric boundary layer dynamical conditions including, but not limited to the following: parameterization and scaling of boundary-layer processes for microscale and mesoscale predictive models; surface conditions from simple to heterogeneous terrain elevation and slope, vegetation, and moisture; surface energy budgets; scale interactions; temperature and moisture fluctuations, especially as they affect the atmosphere as a medium for propagation of acoustic and electromagnetic signals; and natural or induced obstructions to visibility. One principal focus of boundary-layer dynamics is their application to prediction of the mean and fluctuating concentrations of chemical and biological agents in realistic terrains on appropriate scales. Research topics are considered from perspectives of theory, field experiments, and analyses of the faithfulness and validity of models and simulations of these processes. The research results are expected to contribute to improved models of boundary layer processes for visualization and field use through strong interactions with appropriate Army laboratory scientists.

2.2.3 Management of Atmospheric Information. Providing useful atmospheric information to the soldier and decision maker is the ultimate goal of the Army's atmospheric sciences effort. The information needs of each user may be very different. Furthermore, the information must be in a form that is readily understood in light of the user's needs. At the same time, the path from data to information must have a fundamental scientific basis. The science issues behind information

management include an ability to obtain data from multiple sources, friendly or adverse, quantitative and qualitative; fusing the data into a comprehensive representation of the present and future atmospheric state; understanding of the uncertainties of the data and their effects on the application; and communicating the complex four-dimensional atmosphere in the language and application of the user. To accomplish the goals of information management, improved techniques are needed to assimilate and integrate the data, assess the atmospheric present and future state, and disseminate the user's needed information in a timely and effective manner.

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2.3 Habitation Science. Habitation Science is basic research that will allow the Army to project power around the globe in a mode that supports operational needs in a sustainable manner. Program interests include rapid start-up of biological processes; membrane processes for water purification; advanced barriers and structures; real-time informatics and analysis; energy recovery and conversion; and resource reuse and transformation. Rapid start-up of biological processes can be defined as sustainable biological systems that incorporate a variety of organisms (bacteria, algae, plants etc) to regenerate air, water and food so as to support forward base camp self-sufficiency. Forward osmosis (FO), membrane distillation (MD) processes, and membrane development hold potential interest. Also, of interest would be advanced system multi-functional design with conceptualization of systems possessing redundancy, integration, and poly-functional materials viewed in the context of systems inhabited by soldiers. Basic research into unit operations that hold the potential to continuously accommodate troops of variable population sizes and perform equally in urban and remote locations under a wide range of climates is of interest. The need exists for basic research that examines systems that maximize recovery of usable energy via physical-chemical and biological processes. Such operations need to simultaneously minimize system mass, volume and power while controlling the amount, composition and release of reaction by-products.
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c. RESEARCH AREA 3: MATHEMATICS

3.0 Mathematics. Mathematical language, theory, and methods pervade research, development, testing, and evaluation encountered by the Army and the academic disciplines in science, engineering, and technology. Furthermore, increased demands are being placed on the mathematical sciences because of its role in building a foundation for emerging sciences and technologies in the information, network, life, decision, and social sciences. Although these problems are often naturally stated in terms of their disciplinary context, their solutions are often dependent on new mathematical results and theories. For example, promising approaches to computer vision for automatic target recognition (ATR) require research in a wide range of mathematics including constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, probabilistic algorithms, and distributed parallel computation. In the area of modeling and simulation of large-scale systems (systems of systems approach), improvements in model fidelity and capacity depend on the mathematics of optimization, stochastic methods, large scale scientific computing and real time computing for embedded

systems. Similarly, advances in robotic and sensor systems depend on mathematics of dynamics, control, communication, logic, cooperation, and complexity. In order to respond to these increasing demands on the mathematical sciences, the ARO supports and advances fundamental research and knowledge that focuses on the needs of the Army. To accomplish this objective, the Division supports extramural basic research in the four areas that follow. The research supported by the Division does not cover all the topics in these areas, but only those areas that are of strategic importance for the Army. The sub disciplinary boundaries within the Division and the disciplinary boundaries in the ARO are not rigidly drawn and there is strong interest in and appreciation for multidisciplinary research in which the mathematical sciences play a major role.

3.1 Modeling of Complex Systems. The Modeling of Complex Systems Program is a program of fundamental mathematics-oriented research, the objectives of which are to develop quantitative models of complex phenomena in two areas in which current models are not fully based on first/basic principles and in which metrics based on first/basic principles are not yet well known. The two areas of interest to the Modeling of Complex Systems Program are 1) geometric and topological modeling and 2) small-group social and sociolinguistic modeling. Complete and consistent mathematical analytical frameworks for the modeling effort are the preferred context for the research, but research that does not take place in such frameworks can be considered if the phenomena are so complex that such frameworks are not feasible. Metrics are part of the mathematical framework and are of great interest. Traditional metrics, when they exist, often do not measure the characteristics in which observers in general and the Army in particular are interested. For many complex phenomena, new metrics need to be developed at the same time as new models. Just as is the case for the modeling effort, these metrics should preferably be in a complete mathematical analytical framework. The research in modeling of and metrics for complex phenomena supported by the Modeling of Complex Systems Program is mainly mathematical analysis (not computational mathematics).

The two major areas of research of the Modeling of Complex Systems Program are:

3.1.1 Geometric and Topological Modeling. Representation of complex, irregular geometric objects and of complicated, often high-dimensional abstract phenomena and functions is fundamental for Army, DoD and civilian needs in modeling of urban and natural terrain, geophysical features, biological objects (including humans and their clothing), information flow and many other objects and functions. Real-time representation and visualization of 3D terrain (not just as a height field but with multivalent height functions and non-genus-0 topology) directly from real-time or stored point-cloud data cannot be achieved with current techniques. A key to achieving this goal is data compression at ratios and with accuracy that strongly exceed what is currently available. A multitude of variants of piecewise planar surfaces (including those on triangulated irregular networks or “TINs” and triangular mesh surfaces or “TMSs”), splines, multiquadrics, kriging, wavelets, neural nets and many other techniques developed in the past perform well on many types of data. However, none of these procedures are able to provide, without human intervention, representation of irregular objects and functions with the accuracy and compression that is needed. New approximation theory that does not require the assumptions (primarily smoothness) of classical approximation theory and that provides structure for the many new non-smooth approximation techniques currently under investigation is required. Research on the metrics in which approximation should take place is needed. Approximation

theory for information flow and other abstract phenomena in large wireless communication, sensor and social networks is of interest. The approximation theory developed under support of this program is expected to provide building blocks for computational geometry, pattern recognition, automatic target recognition, visualization systems, information processing and network information flow.

3.1.2 Small-group Social and Sociolinguistic Modeling. Quantitative, analytical models of small social groups and of sociolinguistic phenomena are required for operations, training, simulation (computer generated forces) and mission planning. Current models have limited accuracy. Research focused on mathematically justified, practically useful, computationally tractable and data-tractable models is needed. ("Data-tractable" means "does not require more data or more detailed data than is realistically likely to be available."). Research on the metrics in which the accuracy of the models should be measured is needed. A potential area of interest is the mathematical analysis of language (and possibly other elements in communication processes such as frequency of message exchanges, format of communication, etc.) with the goal of extracting/deriving non-linguistic information such as social structure. This area of investigation is distinct from language translation and computational linguistics.

"Metrics" (distance functions in generalized sense, not in the classical mathematical sense) derived from human-based goals are a cross-cutting theme in this research. New metrics should be derived from the fundamental principles that are at the core of the human activities being investigated and should not simply be chosen or imposed on the model.

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3.2 Probability and Statistics. The Probability and Statistics program supports extramural basic research in stochastic analysis and control, and statistical analysis and methods in response to the Army's need for real-time decision making under uncertainty and for the test and evaluation of systems in development. Special emphasis is placed on methods for analyzing data obtained from phenomena modeled by such processes. The two major areas of research are described below.

3.2.1 Stochastic Analysis and Control. Many Army research and development programs place emphases on modeling, analysis, and control of stochastic dynamical systems. Such problems generate a need for research in stochastic processes, random fields, and/or stochastic differential equations in finite or infinite dimensions. The research concentration areas in stochastic analysis and control thrust include but are not limited to the following:

a. Stochastic Partial Differential Equations. Research on analytical and approximation methods for solving stochastic delay and stochastic partial differential equations and their related nonlinear filtering and control problems is one of the program objectives. The Hamilton-Jacobi-Bellman theory via dynamical programming principle and/or necessary optimality conditions in terms of maximum principles have yet to be developed for optimal control of these infinite dimensional equations. Modeling of rare event analysis of spatial-temporal random phenomenon requires a fundamental

mathematical understanding of the theory of large deviations for infinite-dimensional stochastic dynamical systems, in particular stochastic partial differential equations driven by Brownian and/or Poisson space time noises.

b. Measure-Valued Stochastic Processes. An emerging and mathematically challenging area is the study of measure-valued process models of stochastic networks. One of the goals of this program is to develop general tools for the study of these processes, and their application to gain insight into the performance analysis, stability, control and design of this class of network models.

c. Weakly Interacting Stochastic Systems: Many physical and engineering systems can be modeled as a large collection of stochastically evolving agents or particles, whose dynamics are weakly coupled by an interaction that depends only on the empirical measure or distribution of the particles. The design and control of these systems give rise to many mathematically challenging questions. Among the many areas where progress is needed, the most important include the development of a general methodology to understand the long-time behavior of the solution to the limit measure-valued stochastic equation, and a related analysis into the implications of the long-time behavior of the limit for the stability or metastability of the stochastic N-particle system. Also of interest are issues of stochastic control, and in particular the design of stochastic controls via Lyapunov function techniques and the interplay between ergodicity and controllability in the stabilization of the stochastic system.

d. Quantum Stochastics and Quantum Control. With technological advances now allowing the possibility of continuous monitoring and rapid manipulations of system at quantum level, there is an increasing awareness of the applications and importance of quantum filtering and quantum control in engineering of quantum states, quantum error correction, quantum information, and quantum computation. To further understand the back action effects of measurements on quantum states and control of the system based on these measurements, mathematical development of non-commutative quantum stochastic calculus, quantum filtering and quantum control theory is necessary. Proposed mathematical research of this nature that has potential applications in quantum information and quantum computation is hereby solicited.

e. Other Areas that Require Stochastic Analytical Tools. Other research areas of importance to the Army in stochastic analysis and applied probability include stochastic fluid dynamics and turbulence.

3.2.2 Statistical Analysis and Methods. The following research areas are of interest to the Army and are important in providing solutions to Army problems:

a. Statistical Testing and Validation of Network Models. The structure (network design), data sets and human element have a major impact on soldier performance. The need exists to develop new statistical techniques and theories to support the selection of optimal designs, validate predictive network models and modify data mining and inferential statistical techniques to use on ill-defined data and improve

measurement. The research concentration areas include dynamical inference of structure in underlying models. In particular, ability to measure reaction of particular features buried in the network and not directly observable, and sequential analysis (changepoint detection) in networks.

b. Reliability and Survivability. To support future network-centric operations, the Army needs novel and efficient statistical tools for improving network reliability and survivability, and for analyzing data collected from sensor networks.

c. Statistical Theory and Techniques for Real Time Analysis of Data Stream. The Army has pressing research needs in the area of streaming data. Especially, sampling theory methodology or the consideration of data epochs with meta-analysis relating findings across epochs may reduce the need to retain the entire stream of information. However, Army analysts frequently have very large or very small data sets sampled from nonstandard, poorly understood distributions. The two situations lead to very different statistical problems. Large data sets may occur in a stream, that is, they may be produced quickly and continually, so that new data compression methods are required to exact and update the relevant information for the decision-maker. On the order hand, in many testing situations, only small amounts of data are available due to cost, time, and safety constraints. The problems to be studied are sometimes vaguely formulated and appropriate models are not developed before acquiring the data. Close collaboration with scientists who work in the field of applications is required to develop new methodologies for addressing the problem of extracting information from meager samples. To extract more information from less data, improved methods for combining information from disparate tests may be needed.

d. Bayesian and Non-parametric Statistics. Future emphasis in statistics on "predictive" models vice explanatory models is important. Military operations call for predictive models based on a growing base of sensor-fueled data stores. Increased computational capability is also leading statistics in a new direction, away from using "classical" results which are really approximations to avoid computational issues. This suggests a need for increased emphasis on research in areas such as robust statistics, non-parametric statistics, non-linear models etc.

e. Statistical Analysis of Very Large and Very Small Data Sets. The state-of-the-art in statistical methods is well adapted to elicit information from medium-size data sets collected under reasonable conditions from moderately well-understood statistical distributions. However, Army analysts frequently have very large or very small data sets sampled from nonstandard, poorly understood distributions. Very often the data available does not measure the variable of interest and gives only indirect information. Thus the variable of interest is sampled in some ill-defined fashion. One needs to look at this problem in some generality and develop new theory to handle such problems with ill-defined data.

f. Geometric Methods for Statistical Inference. ARO seeks unifying mathematical frameworks to capture the space of statistical models for inference and learning

purposes. Models using differential geometric insights (such as Information Geometry) to characterize the manifold of probability density functions, to conceptualize measure-valued stochastic processes as paths on such manifold, and to understand the metric of model comparison and selection are welcome.

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3.3 Biomathematics. Biomathematics is an exciting and important new area of activity for ARO. The introduction of biomathematics as a separate area of basic research recognizes the importance and specialized nature of quantitative methods, specifically mechanistic modeling, in the biological sciences. Biology involves a large number of entities that interact with each other and their environment in complex ways and at multiple scales. This complexity makes biomathematics a highly interdisciplinary field that requires unique and highly specialized mathematical competencies to quantify structure in these relationships. In fact, progress in mathematical models of biological systems has traditionally been achieved by making convenient simplifications; major advances in biomathematics research continue to require removing these assumptions (for example, stationarity, ergodicity and deterministic nature) and finding ways to effectively model the real complexity.

Mathematical techniques currently utilized in the field range from agent-based approaches for determining the results of individual behavior, whether those individuals be molecules, zooplankton, or humans, to multi-compartmental modeling in physiology, epidemiology and neurobiology, to network models involved in understanding ecosystem and human social dynamics. Research in control techniques is also valuable for its potential application in militarily important areas such as biowarfare and disease spread. New opportunities to advance the field are found in relatively recent high risk attempts to develop modeling techniques in areas of mathematics not traditionally brought to bear on biological problems, as well as in advances in Bayesian statistics, and a growing recognition that the diffusion approximation is not necessarily adequate for many systems.

The ultimate goal of the Biomathematics Program focuses on using existing mathematics and creating new mathematical techniques to uncover fundamental relationships in biology, spanning different biological systems as well as multiple spatial and temporal scales. Of special interest are mathematical techniques aimed at solving problems that are specific to biological systems, as well as initiatives to find meaning in large amounts of complex data through innovative modeling efforts.

Thrust areas of the Biomathematics Program are as follows:

3.3.1 Fundamental Laws of Biology. The field of physics has long been "mathematized" so that fundamental principles such as Newton's Laws are not considered the application of mathematics to physics but actually physics itself. The field of biology is far behind physics in this respect; a similar process of mathematization is a basic and high-risk goal of the ARO Biomathematics Program. The identification and mathematical formulation of the fundamental principles of biological structure, function, and development applying across systems and scales

will not only revolutionize the field of biology but will motivate the creation of new mathematics that will contribute in as-yet-unforeseen ways to biology and the field of mathematics itself.

3.3.2 Computational Cell and Molecular Biology. The currently increasing ability to generate large volumes of biological data provides a significant opportunity for biomathematical modelers to develop advanced analytical procedures to handle these data. This thrust area attempts to elucidate the fundamental principles by which biological elements at different scales (genes, proteins, cells, etc.) are integrated and function as systems through the use of innovative mathematical and statistical techniques. The task is complicated by the fact that data collection methods are noisy, many biological mechanisms are not well understood, and, somewhat ironically, large volumes of data tend to obscure meaningful relationships. However, traditionally "pure" math methods such as differential geometry, algebra and topology, integration of Bayesian statistical methods with mathematical methods, and the new field of topological data analysis, among others, show promise in approaching these problems.

3.3.3 Multiscale Modeling/Inverse Problems. Biological systems function through diversity, with large scale function emerging from the collective behavior of smaller scale heterogeneous elements. This "forward" problem includes creating mechanistic mathematical models at different biological scales and synchronizing their connections from one level of organization to another, as well as an important subproblem, how to represent the heterogeneity of individual elements and how much heterogeneity to include in the model. Solutions will elucidate the connection, for example, of stem cells to tissue and organ development or of disease processes within the human body to the behavior of epidemics. The "inverse" problem is just as important as the forward problem. From an understanding of the overall behavior of a system, is it possible to determine something of the nature of the individual elements? For example, from knowledge of cell signaling, can we go back and retrieve information about the cell? Although inverse problems have been studied for a long time, significant progress has been elusive. This thrust area involves innovations in spatial and/or temporal modeling of multi-level biological elements with the goal of achieving a deeper understanding of biological systems and eventually connecting top-down (data-driven) and bottom-up (model-based) approaches.

3.3.4 Modeling at Intermediate Timescales. Biological processes operate at a variety of timescales; understanding the dynamics of a system at intermediate timescales, as opposed to its long term, asymptotic behavior, is critically important in biology, more so than in many other fields. For example, an epidemic is a necessarily transient phenomenon. In addition, deterministic models are an approximation that often is not good enough to be informative about the system. Yet, intermediate timescales of nonlinear dynamics with stochasticity, both internal and external, are not well understood. This thrust area attempts to fill the gap in the basic understanding of modeling of systems, as well as their control, at intermediate timescales.

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3.4 Numerical Analysis. Numerical computation has become an essential part of both scientific inquiry and of engineering design. It is now possible to simulate potential designs and analyze failures after they have occurred. Such simulations often require considerable effort to set up,

considerable computer time and memory on large scale parallel systems and considerable effort to distill useful information from the massive data sets which result. In addition, it is not often possible to quantify how well the models simulate the real problem or how accurate the simulation is. This problem is especially acute for simulations of failure processes. Data has become ubiquitous but mathematically sound methods for incorporating the data into accurate simulations are lacking. Finally, simulations are often not timely. The most recent example of this is the Corps of Engineers' inability to predict with enough reliability that the levees in New Orleans would fail before they did. The emphasis in the Computational Mathematics program is on mathematical research directed towards overcoming these and related shortcomings.

3.4.1 For problems that are not time-limited, research areas of interest include but are not limited to the following:

1. Advances in Numerical Analysis. New methodologies are required for solving currently intractable Army problems. Advances which reduce computer time, are amenable to implementation on advanced computer architectures, are robust and have high order accuracy are of interest. Rigorous analysis is needed to determine structure, predict performance and drive adaptivity.

2. Multi-scale methods. More and more, problems of interest to the Army are characterized by the fact that behavior at microscopic scales has a large influence on performance of systems. To solve these problems, algorithms are needed to deal with different mathematical models at different scales, interacting subsystems, and coupling between models and scales. The emphasis is on mathematical methods which have universal application rather than methods applicable only to specific problem areas.

3. Verification and Validation. Models used for simulation may not be accurate due to uncertainties in the models themselves or uncertainties in parameters or interactions among components. Likewise, analytical and computational methods are needed to quantify errors generated by the translation of a model to a computer algorithm, the choice of parameters in the algorithm and the execution of the algorithm. Systematic methods are needed to evaluate and quantify these and other sources of uncertainty. The emphasis is on determining the accuracy of the entire simulation, not just on a particular computer code.

4. Data Driven Simulations. Advances in sensors and signal processing have greatly increased the amount of data available to scientists and engineers. The type of information which can be distilled from this data is different from and complements that generated by numerical simulation. If these two modes of investigation could be combined, it might be possible to obtain information unavailable to either mode acting alone. Uncertainties and incompatibilities between data and simulation make such combinations difficult. There is considerable interest in mathematical methods for combining data with simulation.

5. Supporting Technologies. As numerical computations become larger and more complex, the non-numerical issues become more important. Computers have heterogeneous architectures, multiple processors, and complex memory hierarchies. Data is distributed among multiple computers connected to each other over networks with different bandwidths. Without mathematical tools that map algorithms to architectures with minimal input from programmers and users, computation on such systems is difficult and time consuming. In addition, large scale computations produce huge data sets. Tools are needed to extract useful information from such data sets and to present results in ways that are easily understood.

3.4.2 Army systems often operate under unpredictable and adverse conditions. In the face of uncertainty, it would be very useful if results could be simulated fast enough to drive decision making, exercise control, and to help avoid disaster. Such simulations need to be created, run, and interpreted in better than real time. While this may not be possible at this time, we seek research directed towards making this goal achievable. Such research should include but is not limited to the following:

Reduced Order Models. At this time, it is not possible to carry out full scale simulations in real time. In order to investigate the behavior of systems under a variety of possible scenarios, many runs need to be made. The only economical way to do this is through reduced order models. Possible methods to create these models include adaptive simplification, methods based on singular value decompositions, and reduced order numerics. All such approaches should be investigated. To be useful, all such models should be equipped with reliable estimates of accuracy.

1. Problem Solving Environments. If decision making is to be driven by simulation, it is necessary to set up simulations very quickly and obtain results in an understandable format. Matlab is one current tool for such a problem solving environment. Are there other approaches?

2. Embedded Simulation. As the size of powerful computers decreases, it should be possible to use simulation to drive control systems. What are the advantages and disadvantages of such an idea? How accurate do such simulations need to be?

3. Decision Making. One valid criticism of numerical simulation is that it takes so long to set up, run, and post-process the results that they cannot be used in a timely manner to guide decision making. The computational mathematics program is interested in any mathematical ideas that can help address this problem.

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d. RESEARCH AREA 4: ELECTRONICS

4.0 Electronics. Electronic components are recognized as key force multipliers in today's Army and will remain so for the foreseeable future. The Electronics Division seeks to support scientific and engineering endeavors in research areas that possess the potential to define new electronic capabilities or to enhance future electronic performance. The Electronic research sub-areas are (1) Solid State Electronics, (2) Optoelectronics, (3) Electronic Sensing, (4) Electromagnetics, Microwaves and Power, and (5) Terahertz Science and Technology. Proposals are sought for research to advance fundamental understanding of electronic processes leading to new or improved materials and devices with a strong prospect for use in future Army technology.

4.1 Solid State Electronics. This research area emphasizes efforts to establish a new and comprehensive base of knowledge for the electronic, photonic, acoustic and magnetic properties of solid-state materials, structures and devices. Functions such as very intelligent surveillance and target acquisition; command, control, and communications; electronic warfare; and reconnaissance, must be accomplished with the high data rates and real-time capability that are essential for these applications. To support the future U.S. Army, these systems will need to operate at much higher speeds and frequencies, have greatly increased functionality, and have much higher levels of integration than present day technology provides. Therefore, fundamental research in the area of Solid State Devices is the corner stone and an essential requirement in the development of these future systems for military defense.

To establish the needed science base for future Army battle-space capabilities, innovative research is sought in the general areas of; novel electronic materials for advanced devices, nanoscale processing and fabrication science, nano/molecular electronic science and technology, nanoscale physical modeling and advanced simulation, ultrafast electronics, advanced device concepts, mixed technologies (electronic, photonic, acoustic & magnetic), heterogenous devices and technologies, micromachined devices and ultra¬low-power technologies. Therefore, the program currently emphasizes fundamental research in, (1) Nanoscale Growth and Processing Science, (2) Nanoscale (Semiconductor) Electronics, (3) Molecular Electronics and (4) Advanced Device Concepts, with a focus towards identifying and overcoming existing scientific barriers. Important science and technological barriers include, but are not limited to, the discovery and implementation of new and revolutionary growth techniques for engineering materials and for mixing and matching diverse material systems; the development of novel processing, fabrication and self-assembly techniques for realizing effective integration of diverse materials and devices into ultra-dense and complex solid-state electronic systems; the establishment of a theoretical base of knowledge into conventional and non-traditional (molecular) nanoscale electronics for bridging the gap between today's microelectronics to the future where molecular devices will be integrated with nanoscale semiconductor devices and components; the development and implementation of accurate physical models and robust simulation tools for identifying novel ultra-small device concepts and complexly-coupled nanosystems and accurately predicting their behavior; the development of a comprehensive science base that will provide fundamental insights into quantum-confined structures with time dynamic, nonequilibrium, dissipative electronic processes that are imbedded in practical circuits with realistic interconnects; and the development of new and effective integration techniques for

realizing complex heterogeneous devices (i.e., devices utilizing different materials and operating on different physical principals) and mixed technology systems.

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4.2 Optoelectronics. Research in this subarea includes novel semiconductor structures, processing techniques, and integrated optical components. The generation, guidance and control of UV through infrared signals in semiconductor, dielectric, and metallic materials are of interest. The Army has semiconductor laser research opportunities based on low dimensional semiconductor structures (quantum dots, wells, wires, etc.) operating in the eye-safe (>1.55), 3-5, 8-12, and 18-24 microns regions for various applications, such as ladar, IR countermeasures, and free space/integrated data links. Components and sources in the UV/visible spectral ranges (particularly < 300 nm) may be of interest as well. Research is necessary in semiconductor materials growth and device processing to improve the efficiency and reliability of the output of devices at these wavelengths.

High performance devices and components will be optimized for applications including high data-rate optical networks. Interfacing of optoelectronic devices with electronic processors will be investigated for full utilization of available bandwidth. Electro-optic components will be studied for use in guided wave data links for interconnections and optoelectronic integration, all requirements for high speed full situational awareness. Optical interconnect components are needed in guided-wave data links for computer interconnection and in free-space links for optical switching and processing. For high-speed optical signal processing as well as potential for power scaling, research on individual and 1 or 2-D arrays of surface or edge-emitting lasers is necessary. Research addressing efficient, novel optical components for high speed switching based on plasmonics, quantum dots, metamaterials or other regimes may be of interest. Emitters and architectures for novel display and processing of battlefield imagery are important.

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4.3 Electronic Sensing. The ultimate goal of Army sensing is 100% situational awareness to include day/night, all weather, non-line-of-sight and through natural and man-made obstructions for sensing of vehicles, personnel, weapons, chemical and biological threats, projectiles, explosives, landmines, IEDs, and motion. Sensing technologies of interest to this research sub-area currently include acoustic; seismic; passive electromagnetic; magnetic, hyperspectral, and infrared. Novel techniques that enhance the stimulus-response characteristics of nano-structures and semiconductor devices are of interest. Other innovative sensors that meet an Army need are also welcome, however chemical, biological, and radar sensing techniques are generally funded through other sub-areas as is image processing.

Novel infrared or multispectral detectors and structures are of particular interest. Efforts are sought that raise the operating temperature and reduce the cost of “cooled” high performance infrared detectors, as well as, efforts that increase performance of “uncooled” infrared detectors. Research opportunities include components based on quantum confined devices and

semiconductor materials operating in the infrared 1-24 microns regions. Also of interest is the ultra-violet spectral region. In both regions, fundamental studies involving growth, defects, interfaces, substrates, doping, and other electronic characteristics will be considered.

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4.4 Electromagnetics, Microwaves, and Power. Army Transformation is driving the need for basic research supporting mobile, multifunctional, reliable, and high-performance communications and sensor systems. This research falls into the following general technical areas: computational electromagnetics, antennas, RF and microwave component development, RF and microwave circuit integration, landmine/UXO/IED detection, energy-efficient high-frequency components and circuits, and high-power devices for power distribution and control.

Problems of interest in computational electromagnetics can be divided into two regimes: device, circuit, package, and antenna modeling at short length scales, and radio wave propagation modeling at large length scales.

Advanced models and simulations tools must be developed to accurately predict device, circuit, package, antenna, and system performance. Of special interest are physically-based models that enable the simulation of integrated circuits and modules as the levels of integration increase and as the circuits become denser and more complex. The coupling of radiation into and out of complex structures is a problem of special interest. New analysis concepts, techniques, and methodologies are needed with improvements in algorithm speed and efficiency including model order reduction, design for inherently low computational dispersion, and hardware acceleration. The human interface for these tools should simplify the problem setup, data presentation and analysis process, possibly including knowledge-based tools enabling the integration of multiple computational engines.

Propagation effects have a major impact on communications and radar systems. Research is sought leading to innovative and efficient techniques for near-real-time propagation modeling, capable of point-to-point calculations over paths that include urban, rural, and foliated environments with natural and man-made structures including tunnels, validated with appropriate experimental data, with effective interactivity and information delivery to the user.

Innovative approaches are needed to increase the performance and decrease the size and signature of tactical antennas operating from the HF to W frequency bands. Novel and new materials, configurations, and fabrication techniques for multifrequency, multiband operation are of interest. This will require fast frequency switching circuits and techniques for tunable antennas that minimize nonlinear effects over a wide band of frequencies. Radically innovative approaches are needed to increase the performance and reduce the cost of electronically steerable apertures (ESA), including the antenna elements and ancillary components. Ultimately, completely new approaches are sought for a new class of antenna elements that are efficient point sensors and radiators of the vector electromagnetic fields with little or no mutual coupling for highly oversampled antenna arrays giving improved direction finding capabilities and radiation pattern control.

The electronic systems of the future will operate in an increasingly dynamic and complex spectral environment. This drives the need for innovative concepts that will produce devices and components with extremely high dynamic range, extremely wide instantaneous bandwidth, extremely high linearity, and multi-channel phase tracking. These requirements apply to active devices such as power amplifiers and low-noise amplifiers, as well as to passive components such as filters, mixers, couplers, etc. Because these devices and components will be used in mobile systems and because energy storage technology has not kept pace with developments in electronic technologies, the active components must also be energy efficient with low instantaneous peak power requirements and the passive components must have low losses. Optimal partitioning between digital and analog technology combined with new circuit topologies will be critical.

Integration technologies provide millimeter-wave/microwave circuits at small size, lightweight, low cost, and high reliability. Novel techniques for integrating circuits are of special interest at higher frequencies in order to overcome loss, coupling, and spurious radiation problems. Hybrid techniques that combine high performance from component optimization with low fabrication cost due to compatibility with high volume production processes are needed. Fabrication and integration techniques including dense 3-D and heterogeneous integration must be developed that give the system designer access to transmission lines with constant impedance over wide frequency range, inter-layer high-frequency and optical interconnect, hermetic self-packaging, and ease of assembly and handling. Thermal/mechanical effects must be analyzed and minimized. Innovative approaches such as micromachining will provide significant advantages for circuit integration and the production and integration of passive components, including integrated antennas.

Innovative electromagnetic and hybrid approaches are needed for the detection of landmines, unexploded ordnance, and improvised explosive devices. Radar, acoustic electromagnetic induction, gravitometers, nuclear and infrared techniques have been applied in traditional approaches. Innovations on the traditional approaches and hybrid combinations with potential improvements in usability and probability of detection with significant reduction in false alarm rate are of interest to this program.

Research on new and better ways to create and manage power for Army electronic components and systems will reduce the logistics burden on the warfighter. This comprises novel power generation and distribution concepts including biomimetics, distributed generation, and nuclear batteries. It also includes renewable power strategies such as photovoltaics and energy harvesting, but does not include chemical battery or fuel cell technology. Research into the design of low peak power, highly efficient circuits and protocols for communications, radar transmitters, unattended ground sensors, and soldier electronics is of interest, as is research on high power management systems for all-electric vehicles, directed energy systems, and high energy lasers.

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4.5 Terahertz Science & Technology. This research area emphasizes efforts to establish a new scientific foundation for understanding and utilizing terahertz (THz) frequency sensing as a new tool for the detection, identification and characterization of chemical and biological (CB) agents on the battlefield. This research area also includes a parallel thrust to identify and develop advanced device concepts that are suitable for realizing THz-frequency sensors and sensor systems that are militarily useful (i.e., compact, robust, cost effect, etc.) in realistic battlefield scenarios.

To establish the needed science and technology base for future Army battle-space capabilities, innovative research is sought in the general areas of THz frequency sensing science and advanced device concepts that facilitate robust functionality at frequencies within the submillimeter-wave or THz frequency regimes (i.e., the part of the electromagnetic spectrum between approximately 1 mm (300 GHz) and 100 μm (3 THz). To improve device performance, the Army is interested in new device and circuit concepts, including quantum transport devices such as resonant tunneling structures and quantum-transition devices in which photon emission can occur through intersubband transitions between quasi-bound states. It also includes traditional devices with revolutionary circuit and packaging techniques to improve performance. The components of particular interest are electrically-driven room-temperature sources, cw or pulsed, operating between ~ 0.3 and 3 THz. Innovative and novel methodologies should be explored until an effective approach is discovered or developed. Here, the development of efficient sources and integrated semiconductor-based components and systems is a priority.

In addition, a key application of interest for terahertz and ultrafast electronics is battlefield remote sensing of biological agents. Another second class of application is point detection of biological/chemical agents and explosives, such as RDX and TNT that also interact with THz radiation via low-frequency vibrations and rotational modes. Rapid, unambiguous identification of chemical agents, precursors, and degradation products is required in many areas of the DoD including treaty verification and counter¬terrorism. The ultra-high resolution offered by THz spectroscopy may provide this rapid identification even when the substance is in a complex mixture. A final, and possibly even more far-reaching application of THz electronics, is in the development of concepts for extending ultra-wideband sensing and communications. Indeed, the fusion of an advanced THz-frequency sensing capability with conventional sensor-network communications and high-speed data processing has the potential for significantly enhancing the network-centric capability of future Army systems. Here, THz electronics will collectively impact spectroscopic sensing, radiometric imaging and data transmission/processing. Furthermore, commercial local-area-wireless networks can already be envisioned at frequencies as high as 400 GHz, therefore, THz electronics has a strong duel use potential and the potential for significantly impacting the high-frequency electronics of the future.

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e. RESEARCH AREA 5: COMPUTING SCIENCE

5.0 Computing Science. The principal objective of the ARO Computing Science Division is to provide increased performance and capability for processing signals and data, and to extract

critical information and actionable intelligence to enhance the warfighters' situation awareness, decision making, command and control, and weapons systems performance. The division supports research efforts to advance the Army and nation's knowledge and understanding of the fundamental knowledge, principles, and techniques governing intelligent and trusted computing. More specifically, the division aims to promote basic research studies to establish new computing architectures and models for intelligent computing, to create novel data fusion and extraction techniques for efficient information processing, and to build resilient computing systems for mission assurance. The results of these research efforts will stimulate future studies and help to keep the U.S. at the forefront of research in the computing sciences. The research topics described in this section of the BAA are those needed to provide the warfighters with the latest information science technology needed to achieve the vision of future Army operations.

5.1 Computational Architectures and Visualization. The Computational Architectures and Visualization program is concerned with modeling, analysis, design, and validation of computational infrastructure (hardware and software) with special emphasis on the effect emerging and future computational architectures will have on managing, processing, analyzing, and visualizing massive data sets. This is due to the fact that the Army's ability to generate data of all types from the battlefield to the laboratory far outpaces the Army's ability to efficiently manage, process, analyze, and visualize such massive amounts of information. Emerging architectures only exacerbate the problem because the present and traditional models of computation no longer apply. Specific areas of interest can be found in the following two paragraphs.

5.1.1 Computational Architectures. Future computer systems will be both massively heterogeneous and parallel implying the present and traditional models of computation will no longer be applicable. As a result, this thrust supports the development of new computational theories, mathematical abstractions, and models of computation needed to address the difficulties associated with heterogeneous, parallel and distributed processing. Of special interest is determining how these new abstractions, algorithms, and computational processes map onto emerging computational resources of different types (e.g., multi-core, quantum, cloud, and chaotic computing, and determining which platforms are most suitable for Army applications). Other important issues to be considered for these emerging and future architectures are programmability, language and compiler support, real-time scheduling, resource-allocation and the development of a flexible software environment.

5.1.2 Visualization. The visualization thrust of this program is concerned with all aspects of visualization and computer simulation of interest to the Army and is not limited to any one type of data or computer model. Specific research areas of interest are, but not limited to, discrete mathematics, computational geometry, robust geometric computing, graph theory, geometric and solid modeling, interactive graphics, 3D visualization tools, verification & validation, and synthetic environments. Special emphasis is placed on making very large simulations and the visualization of massive data sets faster, more computationally efficient, and more interactive for the user while maintaining an appropriate level of fidelity and physical realism.

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5.2 Information Processing & Fusion. With ubiquitous data acquisition capabilities, effective data and information processing is of increasingly critical importance to defense missions. The Information Processing and Fusion program is concerned with the creation of innovative theories and algorithms for data modeling, data processing, information extraction, and information integration to support the development of real-time decision-making and advanced targeting capabilities for military operations. Emphasis is placed on mathematical theories, methodologies and algorithms for image processing, image understanding, video-based tracking, and data/information fusion. The program consists of four thrust areas as described below.

5.2.1 Foundations of Image and Multimodal Data Analysis. Remote sensing, whether in the visible, infrared or other spectra, presents unique challenges due to a number of operation factors such as clutter, illumination, and occlusion. Innovative research is sought concerning (1) task-oriented representations of multimodal data to enable the understanding of multimodal sensor data and contextual information; (2) detection, localization, and recognition of objects and locations from imaging data with particular emphasis on provable performance guarantees; (3) detection of events, actions, and activities to extract activity-based intelligence, especially when the events are rare and no extensive training data is available; and (4) integrated approaches that enable semantic descriptions of objects and events including relations. Learning and adaptation should be enabled in the representation at both low and high-levels, where inputs from actual users of the systems are used to improve the performance of the algorithms and the fidelity of models at all levels of the modeling hierarchy. Also of interest are methods to exploit the structure of the data and capture its intrinsic dimensionality. The development of an "information/complexity theory" and a "learning theory" specific for remote sensing, imaging data and decision tasks is highly desirable.

5.2.2 Data and Information Fusion. Multimodal data acquisition systems are increasingly prevalent with disparate sensors and other information sources. This thrust seeks advanced mathematical theories and approaches for integrating multimodal data and contextual information to provide actionable intelligence. Of particular interest are systematic and unifying approaches for data and information fusion from diverse sources. Scalable methods are needed for efficiently handling vast amounts of data. Fusion in networked environments addressing issues such as adaptive, distributed and cooperative fusion is emphasized. Theories and principles for performance analysis and guarantees at all fusion levels to support robust data and information fusion are important to ensuring successful military operations.

5.2.3 Active and Collaborative Sensing. Modern sensing systems typically include multiple networked sensors with communication capabilities where the whole network can be thought of as a sensor that can be controlled, in addition to each individual node having some controllable degrees of freedom such as mobility for unmanned aerial/ground systems, pan-tilt-zoom for infrastructure sensors, or waveform for agile radar. Depending on the task or query, it is desirable for the system to control the data acquisition process so as to acquire the "most informative data" for the specific task or query. Consequently, research is solicited to address the integration of mobility, sensor-selection, modality selection, and active observation for real-time assessment and improvements of sensing performance. Another research area of interest is performance-driven active data collection. A query is given to the system together with a desired

performance bound. Where the confidence in answering the query is insufficient, the system should actively interrogate or control sensors so as to achieve the desired confidence. Such an active learning and information-driven sensor control must include the soldier in the feedback loop.

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5.3 Information and Software Assurance. From the Army perspective, Information Assurance must provide authentic, accurate, secure, reliable, timely information to warfighters in order to achieve information dominance, regardless of threat conditions. Computing and information processes may be carried out over distributed and heterogeneous systems, which may include mobile computing and communications systems, and high performance information process systems that are inter-connected through both tactical and strategic communication systems.

5.3.1 Supporting Army Tactical Mission. Research is needed in the areas of protocols and techniques that would assure delivery of trustworthy data to support battlefield missions. Reconfigurable, survivable, and self-healing systems allow a combat unit to dynamically establish and maintain its command and communication capability under diversified and extreme battlefield situations. The Army requires a fully mobile, fully-communicating, agile, and situation-aware force that operates in a highly dynamic, network centric environment. This force consists of a heterogeneous mixture of individual soldiers, ground vehicles, airborne platforms, unmanned aerial vehicles, robotics, and unattended sensor networks that operate in a complex wireless environment. Information theory has played a founding role in the study of security. Across a wide range of application domains and security objectives, information theory leads to insight to the underlying tradeoffs between security and performance. The Army seeks novel ideas in fundamental research areas such as information-theoretic security and the science of security that will provide direct guidance in the design of secure tactical wireless systems. In particular, topics of interest include new paradigms for physical layer security (ranging from confidentiality to authentication to trustworthiness in physical layer communications), the fundamental bounds in key management in distributed systems, and the exploitation of key establishment and distribution protocols. The corresponding constructions that would arise from such an investigation represent a significant avenue for improving future wireless systems as well as the corresponding secrecy capacity limits that could be obtained from such an investigation serve as valuable guidelines in developing future wireless systems with confidential and authenticated communications. New computing and communication protocols and techniques are needed to assure critical information processing and delivery even when such systems are under severe resource constraints.

5.3.2 Foundations for next generation survivable systems. The field of information assurance needs a foundational science to guide the design of systems and to quantitatively measure safety and the level of assurance of complex systems that we depend upon today. Assurance principles and metrics are needed to help define, develop, and evaluate future robust and resilient systems and network architectures that would survive sophisticated attacks and intrusions with measurable confidence. We seek the capability to measure a complex system and to produce a scalar value that can determine the trustworthiness of that system. In addition, human users need

to be in the loop for system assurance analysis. Developing human centric security-usability metrics, computational models for usable security in stressful situations, and adaptive security protocols according to perceived threats are some of the research areas of interest in improving warfighter performance while maintaining sufficient security requirements. One new challenging area of research that offers great promise in stronger system robustness is the modeling of adversaries, since ultimately systems need to defend effectively against their attacks. A deeper understanding and more accurate modeling of adversarial behaviors lead to better future system development.

5.3.3 Trusted social computing. Cheaper but more powerful computing devices and ubiquitous wireless communication have profoundly changed our way of life, and transformed computing from being data processing centric in the past to being human centric now. Though social computing applications have grown rapidly, understandings on trust and assurance principles for social computing remain very limited, with no quantitative models for reliable trust determination and validation. A need exists to gain an understanding on the impact of social dynamics on trust, to explore and analyze the representation of human interaction via social protocols and collaboration patterns in social networks via parameters informed by social sciences and economics, to establish trust theories and a framework for human centric computing, to build metrics and quantitative models for determining levels of trust and implications of such trust values, and to develop new techniques for trust management and automated trust determination for multi-dimensional social computing. Social networking and social media have created an enormous amount of data (text, image and video) that contains a tremendous amount of information that can be exploited for various applications such as situational awareness and intelligence gathering. A need exists for reliable, trustworthy models and analytical tools that can be used to guide the development of new methodologies for social-media-based data sensing and processing, given that social media data can easily be forged, manipulated or fabricated.

5.3.4 Principles of Moving Target Defense. Current cyber defenses are often static and governed by lengthy processes, while adversaries can plan their attacks carefully over time and launch the attacks at cyber speeds at times of their choosing. We seek a new class of defensive strategies to present adversaries with a moving target where the attack surface of a system keeps changing. Although such an idea of a "moving target" is a powerful paradigm for building systems robust to security threats, many fundamental aspects associated with such a strategy need to be further investigated and understood. For example, such a "moving target" system may operate under many different contexts, ranging from the use of frequency hopping in spread spectrum to software diversification. It is critical to establish new theories and models that can provide trade-off analysis between system robustness against attacks vs. performance/usability, and quantify the risks associated with system adaptation under an adversarial setting. Ultimately the understandings and analytical models obtained will establish an important foundation for creating robust tactical systems capable of maximizing the difficulties for the adversaries to attack while minimizing the impact to system performance and usability.

5.3.5 Hardware Assurance. Assuming the trustworthiness of underlying hardware, current information systems typically implement security services in software that provide authenticity, integrity and confidentiality of information; however this assumption is increasingly being

challenged, given the current globalized, horizontal semiconductor business model. Malicious insertion of Trojan circuits designed (e.g., to act as 'kill switches'), extraction of sensitive IP from an IC using hardware-based side channels, and malicious system disruption and diversion using backdoors in hardware are all real and serious threats to information and cyber-physical infra-structure. In contrast to software assurance, where security risks and vulnerabilities are better studied and understood, understandings on hardware assurance are limited. New hardware analysis models and methodologies are needed to carry out correctness verification and to detect malicious logic insertion that could happen either in hardware design specification or during chip fabrication. Emergent properties of silicon chips such as Physically Unclonable Functions (PUFs) provide a promising mechanism for IC identification, authentication and potential on-chip key generation. Novel techniques are also sought that can minimize side channel information leakage from the IC and help establish tamper proof to eliminate physical access to the chip/system from an unauthorized user.

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5.4 Social Informatics. Technologically enabled social interaction has had explosive growth over the past several years. Social media in general and the Internet in particular facilitate social interaction and information exchange at high levels that were previously not available. They have created and continue to create an enormous amount of data (text, image and video) and information that can be exploited for various applications, such as situational awareness and intelligence gathering. Traditional models and analytical tools for physical phenomena often do not work for social phenomena. One salient difference is in trust. It is normally assumed that information about physical phenomena can be trusted (perhaps with limitations). However, one can never fully trust the information from technologically based social media since they can easily be and are commonly known to be widely forged, manipulated or fabricated. There is a lack of fundamental understanding of how to collect, model and analyze information obtained from social media in a robust and trustworthy way.

The Social Informatics Program is a program of fundamental research the objectives of which are to quantify technology-based social interaction phenomena, to develop metrics for the quantified phenomena and to develop forensic and predictive analytical and computational models based on these quantifications and metrics. The objects of interest will generally be social phenomena (social groups/structure) and socio-cognitive phenomena (human intentions in a social context). The quantification and metrics of interest to this program are those based on domain-scientific principles of social and socio-cognitive science that are at the same time mathematically consistent and computationally feasible.

The research of interest to the Social Informatics Program includes quantified, analysis-based research about technology-based social interaction phenomena in the following two areas:

5.4.1 Quantification and Metrics. Extraction of information from social media requires research in quantification of and metrics for these phenomena. The metrics by which one measures distance between phenomena will likely be nontraditional. Here, the word "metric" means simply a general distance measure, not a "metric" in the classical mathematical meaning of the

word. In particular, a metric need not fulfill the triangle inequality, an inequality that does not seem to correspond to many social or socio-cognitive phenomena, and need not be symmetric, that is, the distance from y to x may be different from the distance from x to y. Traditional metrics, when they exist, often do not meaningfully measure the social or socio-cognitive phenomena in which observers in general and the Army in particular are interested. All metrics should be computationally feasible, mathematically justified and based on known or hypothesized sociological or socio-cognitive principles. Ad hoc or purely heuristic metrics are insufficient. The metrics need to be derived, not assumed or assigned. Quantification and metrics need to extend to reliability and accuracy, since falsification and deception are often present at the level of the input into the social medium by a human being. Processing of soft information such as text and voice has been extensively investigated, but insufficiently in the social context which often determines meaning and which can resolve ambiguities.

5.4.2 Analytical and Computational Models. Of interest are analytical and computational models for both forensic and predictive purposes. These models complement the qualitative models of much of sociological research, especially those in the less-investigated area of weak-tie sociology that is important for technology-based social interaction. The models are dependent on the quantification and metrics discussed in the item above as well as on quantitatively expressed social and socio-cognitive principles. Since such principles are often not yet well understood, they may have to be developed along with the models. Falsification and deception may not be identifiable at the level of input information and may have to be identified by the model. By looking at patterns of information across a variety of sources in an appropriate analytical framework, one may be able to select “true information”, avoid “false information” and produce accurate results. The analytical framework will virtually certainly be deeper and more complicated than weighting (for example, weighting information sources according to ratings or presumed trust), averaging and correlation. The models should be embedded in applicable sociological and socio-cognitive theory and should not simply be computationally descriptive of social-media phenomena and/or be based only on analogies to physical phenomena.

All of the research will need to take place in an open-world context that is significantly different from the closed-world context that has been commonly assumed in the past. Among other questions, there arises the question of what representation of uncertainty is applicable for the poorly understood open-world situations that occur in social-media phenomena. To what extent is classical probability and statistics, which is often an excellent model for well understood closed-world situations, applicable? If it is not applicable, is there evidence that some alternative theory (possibility theory, plausibility theory, various evidence theories, etc.) is applicable? The representation of uncertainty needs to be derived from applicable sociological and socio-cognitive principles, not simply assumed or assigned.

Understanding and being able to predict technology-based social networking and social media phenomena will enhance defense in current and future asymmetric conflict, especially in the technology-based component of that defense.

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f. RESEARCH AREA 6: PHYSICS

6.0 Physics. The objective of the ARO Physics Division is to develop forefront concepts and approaches, particularly exploiting atomic-scale and quantum phenomena, which will in the long-term have revolutionary consequences for Army capabilities, while in the nearer-term providing for existing Army needs. In support of this goal, the interests of the Physics Division are primarily in the following areas: condensed matter physics, quantum information science, atomic and molecular physics, and optics and fields. There is little direct interest in relativity and gravitation, cosmology, elementary particles and fields, nuclear physics, astronomy, or astrophysics, since they generally have little impact on the areas of Army needs. Nevertheless, the possible relevance of topics within these other physics disciplines is not absolutely discounted, and discussions of potential exceptions are welcome.

The disciplinary boundaries of ARO are not sharply drawn, as shown by the joint support of a number of efforts by the Physics Division and other ARO Divisions. In addition, it is not necessary that a potential investigator be associated with a physics department to receive support from the ARO Physics Division.

6.1 Condensed Matter Physics. Condensed matter physics (CMP) is a foundational science enabling fundamental Army technologies in areas such as information processing, communications, sensors, optical components, electronics, optoelectronics, night vision, seekers, countermeasures, and many others. Technologies such as these would not exist today, at least not as we know them, without visionary research in the field of CMP. The ARO CMP Program strives to continue this level of impact by looking beyond the current understanding of natural and designed condensed matter, to lay a foundation for revolutionary technology development for next generation and future generations of warfighters.

6.1.1 Strong Correlations and Novel Quantum Phases of Matter. Understanding, predicting, and experimentally demonstrating novel phases of matter in strongly correlated systems will lay a foundation for new technology paradigms for applications ranging from information processing to sensing to novel functional materials. Interest primarily involves strong correlations of electrons, but those of other particles or excitations are not excluded. This thrust predominantly emphasizes complex oxide heterostructures as a material system in which the discovery, design and control of electronic correlations may be possible. The Program seeks to foster novel experimental and theoretical research targeting the discovery and rational design of new quantum phases of matter, and how excitations within these phases can be probed and controlled.

6.1.2 Topological Electronic Phases in Condensed Matter. Novel quantum phases of electronic matter can also exist apart from strong correlations as recent developments in topological insulators has demonstrated. This thrust seeks to expand the physics embodied in the topology of the electronic structure, including the role of strong correlations and other influences, theoretically predicted or not. Interest emphasizes experimental studies but not to the exclusion of theoretical efforts. Studies in physics and physics-enabling chemistry, such as bulk crystal growth, heteroepitaxial growth modes, and surface chemistry are also of interest.

6.1.3 Unique Instrumentation Development. Advanced studies of CMP phenomena often require unique experimental techniques with tools that are not readily available. The construction and demonstration of new methods for probing and controlling unique phenomena, especially in the studies of novel quantum phases of matter, is of particular interest. Further, structures and assemblies exhibiting unique CMP phenomena may require unique synthetic techniques, which might range from biological assembly to optical lattices. Establishing such techniques for the fabrication or simulation of condensed-matter systems are of interest when they provide access to novel quantum phenomena that are not otherwise readily obtainable.

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6.2 Quantum Information Science. Quantum mechanics provides the opportunity to perform highly non-classical operations that can result in beyond-classical capabilities in imaging, sensing and precision measurements, exponential speed-ups in computation, or ultra-secure transmittal of information. This Program seeks to understand, control, and exploit such non-classical phenomena for revolutionary advances beyond those possible with classical systems. An overarching interest is the exploration of small systems involving small numbers of entangled particles. There are three major areas of interest within this Program.

6.2.1 Fundamental Studies. Experimental investigations, of a fundamental nature of quantum phenomena potentially useful for quantum information science are of interest. Examples include coherence properties, decoherence mechanisms, decoherence mitigation, entanglement creation and measurement, nondestructive measurement, complex quantum state manipulation, and quantum feedback. An important objective is to ascertain the limits of our ability to create, control, and utilize quantum information in multiple quantum entities in the presence of noise. Of particular interest is the demonstration of the ability to manipulate quantum coherent states on time scales much faster than the decoherence time. Theoretical analyses of non-classical phenomena may also be of interest if the work is strongly coupled to a specific experimental investigation, such as proof-of-concept demonstrations in atomic, molecular, and optical as well as other systems.

6.2.2 Quantum Sensing, Imaging, and Metrology. This research area seeks to explore, develop, and demonstrate multi-particle coherent systems to enable beyond classical capabilities in imaging, sensing, and metrology. Central to this research area is the exploration of small systems involving a few entangled particles. Topics of interest in this research area include the discovery, exploration, and efficient preparation of multi-particle quantum states advantageous for imaging, sensing, and metrology, processing circuits for these states to enable beyond classical capabilities, and readout to provide the required output. Other research topics of interest are: theory to explore multi-particle quantum states useful for beyond classical capabilities, quantitative assessment of capabilities and comparison to classical systems, efficient state preparation, quantum circuits for processing these states as quantum bits, readout techniques, decoherence mitigation and error-correction for improved performance, supporting algorithms as a basis for processing circuits, connections between the solution of hard computational problems and overcoming classical limitations in imaging, sensing, and

metrology, entanglement as a resource, suitable physical systems and key demonstration experiments.

6.2.3 Quantum Computation & Communication. Quantum computing and communication will entail the control and manipulation of quantum bits with high fidelity. The objective is the experimental demonstration of quantum logic performed on several quantum bits operating simultaneously, which would represent a significant advance toward that ultimate goal of tremendous speed up of computations. Demonstrations of quantum feedback and error correction for multiple quantum bit systems are also of interest. There is particular interest in developing quantum computation algorithms that efficiently solve classically hard problems, and are useful for applications involving resource optimization, imaging, and the simulation of complex physical systems. Input/output interfaces for quantum computation to handle large amounts of classical data efficiently are of interest. The ability to transmit information through quantum entanglements distributed between spatially-separated quantum entities has opened the possibility for an ultra-secure means of communication. Exploration of quantum communication of information based on distributed entanglements such as in quantum teleportation is of interest. In addition, the exploration of long-range quantum entanglements, entanglement transfer among different quantum systems, and long-term quantum memory are also of interest.

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6.3 Atomic and Molecular Physics. Research efforts in the Atomic and Molecular Physics (AMP) Program will create fundamentally new capabilities for the Army, as well as providing the scientific underpinnings to enhance existing technologies. Topics of interest include (i) quantum degenerate atomic gases, both Bose and Fermi, their excitations and properties, including mixed species, mixed state, and molecular, (ii) matter-wave optics and matter-wave lasers, (iii) nonlinear atomic and molecular processes, (iv) quantum control, (v) novel forms and effects of coherence, and (vi) emerging areas. Cooling schemes for molecules are of importance for extending the range of systems that may be exploited. In addition, there is an interest in emerging areas of atomic, molecular, and optical (AMO) physics such as states of protected matter including but not limited to topological phases, emergent lattices in quantum gases, opto-mechanical interfaces, and weak measurements. Research efforts within the AMP Program fall within two thrust areas: Molecular Physics and Generalizations of AMO Physics. It is anticipated that research efforts within these areas will lead to applications including novel materials, robust quantum devices, and novel fieldable quantum sensors.

6.3.1 Molecular Physics. The objective of this thrust is to broaden the scope of atomic physics questions into the molecular regime. Cooling, trapping, and reaching degeneracy of molecules fall into this scope, as well as the interactions between atomic neutrals and molecular ions. Coherent atomic-molecular superposition states, a novel form of matter, and molecules as well as atomic-molecular hybrids in lattices are other examples. The ability to use Feshbach resonances and otherwise tune interactions is also relevant here, both as a mechanism for ultracold molecule production and as a way to cross over from weak coupling to strong coupling regimes (e.g., in superfluidity). As alluded to above, quantum fluids in an optical lattice provide yet more novelty, and offer a forum for investigating open questions in condensed-matter physics as well

as explorations beyond. These include the study of dipolar and more complex molecules and mixed statistics systems in such lattices. The Molecular Physics Thrust is distinguished from programs in the materials and chemical sciences. One distinguishing feature is its focus not on synthesis, but on the underlying mechanisms, such as electronic transport, magnetic response, coherence properties (or their use in molecule formation/selection), control, and/or linear and nonlinear optical properties. The systems of interest are well-defined molecules, generally small or of high symmetry, and their functionalized variants.

6.3.2 Generalizations of AMO Physics. The AMP Program also has a general interest in exploring fundamental atomic and molecular physics topics that may impact future Army capabilities. For example, cold atomic gases interfaced with opto-mechanics provide fundamental research regarding the behavior of macroscopic quantum systems. Future "atomtronic" devices will need to be interfaced in a manner that allows them to perform in noisy environments and remain robust to outside perturbations. General issues of quantum coherence, quantum interference, non-equilibrium phenomena and quantum control, as well as their numerous potential applications are also of interest.

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6.4 Optics and Fields. The Army seeks fundamental physics research that will lead to breakthroughs related to optics and electromagnetism. The objective of this Program is to investigate fundamental physical phenomena that will lead to revolutionary advances in these areas. Through the Optics and Fields Program, the Physics Division emphasizes fundamental science that will significantly improve areas such as remote sensing, information processing, light and energy transmission, and new or emerging phenomena relating to optical physics and fields. Much of the Army's capability in sensing and information and/or energy exchange depends on light. This Program also seeks research for other long-range physical fields that can complement electromagnetic radiation.

6.4.1 Extreme Light. In order to achieve the kinds of breakthroughs described above, this Program seeks research related to extreme light, meaning the examination of light in the extreme limits, such as the shortest pulses attainable and the highest intensity fields attainable. Advances in these areas require theoretical and experimental research. For example, ultrashort pulsed lasers have now achieved intensities of 10^{22} W/cm^2. Future applications of these pulses may include high-harmonic generation, nanolithography, micromachining, particle beam acceleration and control, and light filaments. In the near future, even higher intensities are expected. Theoretical and experimental research efforts are needed to describe and understand how matter behaves under these conditions—from single particle motion and radiation reaction to the effects in materials—and how to generate these pulses and use them effectively. Pulses as short as 80 attoseconds have been produced, and the Program seeks ways to make them shorter and to understand both the physics and applications of this form of radiation. Another example of extreme light is light filaments, where light and plasmas interact to form a new kind of energy propagation. The physics of the interactions as well as many yet to be discovered issues need to be understood, such as how far can light filaments propagate and how much energy can they contain. Proposals for new areas of extreme light are also welcome.

6.4.2 Transformation Optics and Optical Metamaterials. This thrust pursues a fresh start in optics due to the existence of Negative Index Materials and more generally, optical metamaterials. In this area, many conventional limits of optics can be broken, in ways such as sub-wavelength imaging and superlensing related phenomena. It is timely to look at the quantum optics of such processes. This may establish true limits on capabilities and enable one to discover new phenomena not provided by the classical view. New forms of imaging using transformation optics or other novel imaging are also of interest. In general, any optical phenomena that can ultimately improve Army capabilities are sought.

6.4.3 Beyond Light. Any area in fundamental physics that may be exploited to achieve the previously-described Program goals is welcome. For example, modern theories of gravity as well as string theory predict, in addition to gravity, the existence of two other long-range fields. If these theories are correct in their predictions, this suggests applications where electromagnetism and optics fail, such as propagating through conducting media.

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g. RESEARCH AREA 7: CHEMICAL SCIENCES

7.0 Chemical Sciences. The ARO Chemical Sciences Division supports research efforts to advance the Army and Nation's knowledge and understanding of the fundamental properties and processes governing molecules and their interactions in materials and chemical systems. The Division encourages proposals that promote basic research to develop methods for accurately predicting the pathways, intermediates, and energy transfer of specific reactions, to understand the fundamental processes governing electrochemical reactions, to discover the relationships between macromolecular architecture and material properties, and to discover and characterize the many chemical processes that occur at surfaces and in organized assemblies. In addition, these efforts will likely lead to new methods for synthesizing and analyzing molecules and materials that will open the door to future studies not feasible with current approaches.

7.1 Molecular Dynamics. The goal of this Program is to determine the pathways and intermediates for fast reactions of molecules in gas and condensed phases at high temperatures and pressures, and to develop theories that are capable of accurately describing and predicting these phenomena. In the long term, these studies may serve as the basis for the design of future propellants, explosives, and sensors. This Program is divided into two research thrusts: (i) *Reaction Dynamics* and (ii) *Computational Modeling.*

Research efforts in the *Reaction Dynamics* thrust explore energy transfer mechanisms in molecular systems. In particular, research is focused on understanding dynamic processes such as roaming radicals, chemical reactions in solid state crystals and heterogeneous mixtures, phase transformations at extreme conditions, and control of processes using both shaped laser pulses and continuous wave laser beams. Studies that yield new insights on the decomposition pathways of energetic molecules, both in the gas and condensed phases, are also of interest.

Research efforts in the *Computational Modeling* thrust are focused on the development and validation of theories for describing and predicting the properties of chemical reactions and molecular phenomena in gas and condensed phases. In particular, research targeted at the development and implementation of novel theoretical computational chemistry methods is of interest. Ideally, such methods will go beyond current theories to allow for efficient, accurate, and *a priori* prediction of thermochemical properties. Such methods may take advantage of near-ideal parallel processing on massive computer clusters, or they may seek to solve current scaling problems through novel implementation of unprecedented computer algorithms. The accurate prediction of intermolecular forces for problems in solid-state chemistry, such as the prediction of x-ray crystal structures, is also of current interest.

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7.2 Electrochemistry. This Program supports fundamental electrochemical studies to understand and control the physics and chemistry that govern electrochemical redox reactions and transport of species, and how these are coupled with electrode, catalysis, electrolyte, and interface. Research topics include ionic conduction in electrolytes, electrocatalysis, fuelprocessing, interfacial electron transfer, transport through coatings, surface films and polymer electrolytes, and activation of carbon-hydrogen and carbon-carbon bonds. Novel electrochemical synthesis, investigations into the effect of microenvironment on chemical reactivity, and quantitative models of electrochemical systems are also encouraged.

This Program is divided into two research thrusts, although other areas of electrochemical research may be considered: (i) Reduction-oxidation (Redox) Chemistry and Electrocatalysis, and (ii) Transport of Electroactive Species. The Redox Chemistry and Electrocatalysis thrust supports research efforts to understand how material and morphology affect electron transfer and electrocatalysis, tailor electrodes and electrocatalysts at a molecular level, and discover new spectroscopic and electrochemical techniques for probing surfaces and selected species on those surfaces. The Transport of Electroactive Species thrust identifies and supports research to uncover the mechanisms of transport through heterogeneous, charged environments such as polymers and electrolytes, to design tailorable electrolytes based on new polymers and ionic liquids, and to explore new methodologies and computational approaches to study the selective transport of species in charged environments.

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7.3 Polymer Chemistry. The goal of this Program is to understand the molecular-level link between polymer architecture, functionality, composition, and macroscopic properties. Research in this Program may ultimately enable the design and synthesis of polymeric materials that give the Soldier new and improved protective and sensing capabilities and capabilities not yet imagined. This Program is divided into two research thrusts: (i) Synthesis: Architecture and Composition, and (ii) Properties: Linking Molecular to Macroscopic. Within these thrusts, high-risk, high payoff research efforts are identified and supported to pursue the Program's long-term

goal. Additionally, research efforts that connect innovative polymer chemistry with the comprehensive characterization of polymeric materials are of joint interest with the Mechanical Behavior of Materials Program in the ARO Materials Science Division.

Efforts in the Synthesis: Architecture and Composition thrust focus on developing new synthetic approaches for synthesizing polymers with precise control over monomer sequence, branching, and functional group composition and location. Research focuses on new polymerization methodologies, the design and synthesis of new monomers with controlled reactivity, and the design and synthesis of new catalysts that give precision control over polymer structure and composition. Research in the Properties: Linking Molecular to Macroscopic thrust is exploring how changes in molecular structure and composition impact macroscopic properties, such as optical, mechanical, and transport properties. Areas of interest include exploring how polymer branching, chain stiffness, and composition impact macroscopic properties, and on using self assembly to create new, complex polymer structures with new properties.

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7.4 Reactive Chemical Systems. This Program supports basic research with Army relevance in surfaces, catalysis, and organized assemblies. The goals of the Program are to explore reactive chemical systems and related processes such as adsorption, desorption, and the catalytic processes occurring at surfaces and interfaces, and the structure and function of supramolecular assemblies. Through the study of these processes and structures, the Program seeks to develop a molecular level understanding of catalytic reactions, functionalized surfaces, and organized assemblies that may lead to future materials for protection and sensing. The Surfaces and Catalysis thrust supports research on understanding the kinetics and mechanisms of reactions occurring at surfaces and interfaces and the development of new methods to investigate the interactions of small organic molecules and biological molecules on surfaces. Development of reactive multifunctional materials is also included in this Program. A particular area of interest is the interface between nanostructures and biomolecules, including biocolloids, to generate advanced materials. The Organized Assemblies thrust supports research aimed at exploring the properties and capabilities of self-assembled and supramolecular structures, including their functionality, and how to control assembly in different environments. A specific area of interest is the design and understanding of stimuli-responsive materials.

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h. RESEARCH AREA 8: LIFE SCIENCES

8.0 Life Sciences. The ARO Life Sciences Division supports research efforts to advance the Army and Nation's knowledge and understanding of the fundamental properties, principles, and processes governing DNA, RNA, proteins, organelles, prokaryotes, and eukaryotes, as well as multi-species communities, biofilms, individual humans, and groups of humans. The interests of the Life Sciences Division are primarily in the following areas: biochemistry, neuroscience,

microbiology, molecular biology, genetics, genomics, proteomics, epigenetics, systems biology, bioinformatics, and social science. The results of fundamental research supported by this division are expected to enable the creation of new technologies for optimizing warfighters' physical and cognitive performance capabilities, for protecting warfighters, and for creating new Army capabilities in the areas of biomaterials, energy, logistics, and intelligence.

The Division's research programs are currently focused on five research areas. The titles, scopes and points of contact for these programs, each of which address general aspects of basic research in life sciences, are listed below. A small number of symposia, conferences and workshops are also supported in part or in whole to provide an exchange of ideas in areas of Army interest.

8.1 Biochemistry. The Biochemistry Program seeks to understand and control the function, structure, and organization of biomolecules to enable the development of novel systems, materials and processes that enhance Soldier protection and performance. This Program emphasizes innovative high-risk fundamental research in biomolecular self-assembly, molecular recognition and specificity, structure-function relationships, enzymology, biomolecular engineering for novel or enhanced function, sensing and responsive capabilities of biomolecules and cells, mechanisms of biomolecular energy generation and mechanical motion, and molecular and macromolecular organization. Of particular interest are studies exploring the controlled organization of biomolecules at the nanoscale, the integration of biomolecules with synthetic materials or systems, and innovative approaches for supporting biological activity outside of the cellular environment and in non-aqueous conditions.

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8.2 Molecular Genetics. This Program supports basic research in molecular genetics, genomics, epigenetics, and systems biology in areas that may enable the optimization of the Soldier's cognitive and physical performance capabilities, enhance Soldier protection, and improve Army logistics in areas such as biomaterials, energy, and intelligence. This Program emphasizes innovative high-risk fundamental research in areas such as identification and characterization of gene function, gene regulation, genetic interactions, gene pathways, gene expression patterns, epigenetics, mitochondrial regulation and biogenesis, and nuclear and mitochondrial DNA replication, mutagenesis, oxidative stress, and DNA repair. This Program is interested in identifying and understanding the molecular factors that affect human performance and human protection under both normal conditions, and when affected by a variety of stressors that are likely to be encountered in battlefield situations, such as dehydration, heat, cold, sleep deprivation, fatigue, caloric insufficiency, pathogens, and psychological stress. Also of interest are molecular responses to pathogens, pathogen identification, and pathogen inactivation, as well as host-pathogen interactions, host components of infection and resistance to infection, and mechanisms of prokaryotic adaptation. Finally, this Program supports research into biological components of social instability.

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8.3 Microbiology. This Program supports research in microbial physiology, genetics, ecology, and evolution with Army relevance. Included are studies to elucidate antimicrobial resistance mechanisms, microbial community interactions, population dynamics, studies of organisms that are not culturable, studies of organisms at the single cell level, and studies of organisms that have adapted to extreme environments. Of special interest are studies on microbial adaptation to changes in their environment, and studies to enhance stabilization of materiel. Also included are fundamental studies that enable development and exploitation of microbial systems for unique biotechnological applications and bioengineering processes such as by developing innovative approaches to metabolic engineering or protein evolution. Basic mechanisms underlying biodegradation of anthropogenic compounds, mechanisms underlying the synthesis and assembly of biomaterials, and studies of microbiological mechanisms with potential for contributing to the remediation of sites contaminated with toxic wastes will also be considered. Additionally, of joint interest with the Biomathematics Program, are research efforts that advance our ability to work with complex biological data sets to increase understanding of biological systems, ranging from single-cell processes to multi-cellular interactions.

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8.4 Neurophysiology and Cognitive Neuroscience. Research in the perception and cognition subfields of neurophysiology and the cognitive neurosciences, covering several or all areas of electrophysiology, psychophysiology, sensory and perceptual physiology, computational neurobiology, psychophysics, neuropsychology, and integrative neurobiology is of interest. Specific examples can include physiological, neuro-psychological and/or cortical/cognitive mechanisms underlying successful completion of complex task behaviors applicable to non-laboratory environments under non-ideal conditions, including both amelioration of induced losses as well as enhancement in defined perceptual, cognitive and/or motor abilities in healthy humans. Investigations can span the gamut from multi-unit recordings through evoked potentials and neuro-imaging technologies to humoral and psychological correlates of both central and peripheral nervous system function. Non-medically oriented research in both human volunteers and animal models designed to elucidate the fundamental physiology underlying cognition and possible non-invasive methods of monitoring, and using cognitive states and processes during normal activity is appropriate. Perceptual and/or psycho physiological implications of mind-machine interfaces ranging from optimizing auditory, visual and/or somatosensory display, and control systems based on physiological or psychological states through modeling of individual cognitive dynamics is appropriate to this research area.

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8.5 Cultural and Behavioral Science. The goal of this Program is to gain a better theoretical understanding of human behavior through the development of mathematical, computational, statistical, simulation and other models that provide fundamental insights into factors contributing to human socio-cultural dynamics. This Program is divided into two research thrusts: (i) Predicting Human Behavior, and (ii) Complex Human Social Systems. Within these thrusts, high-risk, high pay-off research efforts are identified and supported to pursue the

Program's long-term goal. The Program supports scientific research that focuses on the basic theoretical foundations of human behavior at various levels (individual actors to whole societies) and across various temporal and spatial scales. This includes, but is not limited to, research on the evolution and dynamics of social systems and organizations, human adaptation and response to both natural and human induced perturbations (e.g., global climate change, mass migration, war, attempts at democratization), interactions between human and natural systems, the role of culture and cognition in accounting for variations in human behavior, human decision-making under risk and uncertainty, the search for organizing principles in social networks, and the emergent and latent properties of dynamic social systems and networks. The research involves a wide range of approaches, including computational modeling, mathematical modeling, agent-based simulations, econometric modeling and statistical modeling, to name a few. The Program also recognizes the fact that the building and validation of models in the social sciences is often limited by the availability of adequate and appropriate sources of primary data. Thus some of the supported research includes the collection of primary data for the development and testing of models. Finally the Program also supports research in the development of methodologies (e.g., measurement, data collection, statistical methods, and research designs) that have the potential to help advance our scientific understanding of human behavior. Research focuses on high-risk approaches involving highly complex scientific problems in the social sciences. Despite these risks, the research must have the potential to make significant contributions to the Army through applications that will, for example, improve decision-making at various levels (policy, combat operations), create real-time, computer-based cultural situational awareness systems for tactical decision-making, increase the predictability of adversarial intent, and produce integrated data and modeling in situ for rapid socio-cultural assessment in conflict zones and in humanitarian efforts.

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8.6 Institutional and Organizational Science. The objective of this Program is to understand the emergence, maintenance, and evolution of human organizations and institutions, including but not limited to societies, states, religions, markets, economic systems, legal systems, bureaucracies, political parties, social movements, and formal and informal networks. Currently, subject matter expertise, which varies in quality, and is subjective and unreliable are the main tools of policy and decision makers in this area. Social scientific analysis, when applied, is applied post-hoc once crises are over to provide important insights and lessons learned, but are not employed to anticipate crises or evaluate social change in real time. This is to a large degree because current methods for collecting and analyzing data are too time-consuming and costly to employ until an area of operation and specific research question are identified. Two specific goals of this Program are to (i) identify general theory, abstracted from the details of particular social contexts, to be used universally to anticipate crises or change, and (ii) make data collection and analysis less costly and sufficiently efficient to make feasible the consistent monitoring of events around the globe. Research projects in this Program can include a broad range of approaches including empirical approaches that require primary data collection, such as random control trials, quasi experiments, field experiments, surveys, comparative and observational studies, as well as the use of secondary data sources, such as archival data or news reports, and also formal, mathematical or computational approaches. Of special interest is research on the

reciprocal effect of individuals on institutions and institutions on people: how do institutions shape attitudes and opportunities and constrain behavior, and how do the choices and actions of people and groups, impact and change institutions. The development of a systematic and efficient approach to collect and analyze data to describe fundamental social processes and detect changes in institutional structures can provide military decision makers with the means to understand and anticipate the decisions and activities that impact U.S. interests and national security.

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i. RESEARCH AREA 9: MATERIALS SCIENCE

9.0 Materials Science. The objective of research supported by the Materials Science Division of the ARO is to discover the fundamental relationships that link chemical composition, microstructure, and processing history with the resultant material properties and behavior. The work, although basic in nature, is focused on developing new materials, material processes, and properties that promise to significantly improve the performance, increase the reliability, or reduce the cost of future Army systems. With the need for lighter weight and higher performance systems in the future, program emphasis has increasingly shifted away from metals research to a more balanced program with interests that cross a broad spectrum of materials, including polymers, ceramics and semiconductor materials. Fundamental research that lays the foundation for the design and manufacture of multicomponent systems such as composites, hierarchical materials and "smart materials" is of particular interest.

Other important areas of interest include new approaches for materials processing, new composite formulations, and surface treatments that minimize environmental impacts; and novel composite concepts, including multifunctional and hierarchical materials. Finally, there is general interest in identifying basic research in the area of manufacturing science, which will address fundamental issues related to the reliability and cost (including environmental) associated with the production and long-term operation of Army systems. The following areas of research are not intended to reflect all of the activities of the Materials Science Division; there is always interest in new ideas and cross-disciplinary concepts in materials science that may have future applications for the Army.

9.1 Materials by Design. The goal of the Materials by Design program is to enable the bottom-up design and fabrication of highly complex multifunctional materials with new and unprecedented properties, e.g. negative index composites with optical cloaking properties or new classes of smart materials that can alter their behavior in response to environmental stimuli. In pursuit of this goal the subfield is supporting research that falls into three broad thrusts. The subfield is laying the foundations for future directed self assembly of materials, developing new analytical techniques capable of characterizing materials at the nanoscale, and seeking to understand complex behavior that emerges in highly coupled systems, e.g. studying frustration effects in magnetic systems, or better understanding field coupling effects in multiferroics. It is envisioned that the confluence of these thrusts will culminate in the development of a new generation of engineered materials with new and unique capabilities. To realize this goal the program

recognizes that the experimental program will require a strong complementary theoretical underpinning that addresses modeling of the relevant phenomenology, identification of robust pathways for directed self-assembly, and prediction/optimization of the final material properties. The objective is to predict and control the material structure and properties throughout the self assembly process and affect property changes over time needed to introduce new properties, optimize performance, enhance reliability; and reduce cost and time to development. One area of emphasis will be surface and interface engineering in support of materials integration. There is particular interest in identifying new ways of combining similar and dissimilar materials to afford new multifunctional capabilities. Another area of emphasis will be development of in-situ and ex-situ analytical methods to characterize the nanoscale structure and determine the physical characteristics that will lead to the specific material properties being sought. Two final areas of interest are the development of adaptive materials that change their properties in response to internal or external stimuli, and investigations of novel methods that will lead to large-scale, large-quantity processing of nanomaterials.

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9.2 Mechanical Behavior of Materials. The Mechanical Behavior of Materials program seeks to establish the fundamental relationships between the structure of materials and their mechanical properties as influenced by composition, processing, environment, and loading conditions. The program emphasizes research to develop innovative new materials with unprecedented mechanical, and other complementary properties. Critical to these efforts is the need for new materials science theory that will enable robust predictive computational tools for the analysis and design of materials subjected to a wide range of specific loading conditions, particularly theory which departs from standard computer algorithms and is not dependent upon tremendous computational facilities. The primary research thrust areas of this program include: a) high strain-rate phenomena (e.g., designing new characterization methods and tools to elucidate the deformation behavior of materials exposed to high-strain rate and dynamic loading conditions, establish a detailed understanding of the physical mechanisms that govern this deformation, and realize novel mechanisms of energy absorption and dissipation); and b) materials enhancement theory (e.g., developing a robust understanding of the interrelationships between materials processes and compositions and the range of properties that can be attained by them, particularly in terms of developing new materials theory capable of predicting such processing-property relationships and identifying novel mechanisms for enhancing specific toughness, engineering and synthesizing new materials containing unique and specifically designed chemical and biological functionalities and activities while maintaining, and preferably enhancing, requisite mechanical properties). Two specific examples of research objectives within these thrust areas are stress wave mitigation via highly nonlinear inhomogeneous granular media and mechanochemically adaptive materials based on stress-activated molecules, respectively.

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9.3 Synthesis and Processing of Materials. The Synthesis and Processing of Materials program aims to enable basic studies on innovative processing and synthesis of advanced high

performance structural materials systems. The vision of the program is to discover and illuminate the scientific linkages between novel processing and resultant microstructures which enable exceptional properties in structural materials. Research thrusts specific to this program include: a) synthesis under extreme conditions (e.g. pressures, time-rates, temperatures, strain, length-scales), b) metastable materials processing (bulk nanostructured materials, amorphous metals, non-equilibrium phase stabilization), and c) high specific-strength materials and hierarchical composites. Advances in this area are enabled by insights and scientific breakthroughs achieved through combinations of novel experimental tools (such as nano/microscale 3D tomography and in-situ, multi-variable characterization) and recent computational modeling tools (such as ab-initio/first-principles approaches, phase-field modeling, molecular dynamics simulations) for accurate design and simulation.

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9.4 Physical Properties of Materials. The Physical Properties of Materials program broadly seeks to understand the fundamental mechanisms responsible for various physical properties (such as electronic, optical, magnetic, and thermal properties) of advanced materials. Specifically, basic research efforts in the areas of modeling, innovative processing and characterization techniques to understand the mechanisms responsible for physical properties of materials are supported. There are primarily two research thrusts in this program: (1) Defect Science & Engineering (DS&E) and (2) 2D Free -standing nanostructured materials (2DNM).

In the DS&E thrust, basic research efforts in the areas of introduction, control, and characterization of various defects (dislocations, stacking faults, strain, compositional variations, interfaces, etc.) and their effects on the physical properties (electronic, optical, magnetic and thermal properties) of various materials such as multiferroics, ferro/piezoelectrics, semiconductors, high temperature superconductors, and thermal management materials are supported.

The 2DNM thrust is a new thrust initiated to promote basic research to look beyond graphene to identify novel materials (single elements as well as compounds such as oxides, nitrides, sulfides etc.) that may exist in free-standing mono or a few atomic layer thick form similar to graphene, but with other unique and complementary properties. Fundamental studies to process novel 2D free-standing materials as well as their composites and heterostructures, and research efforts to understand the underlying mechanisms responsible for the revolutionary physical properties of these material systems are focused in this thrust.

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j. RESEARCH AREA 10: NETWORK SCIENCE

10.0 Network Science. Work over the past ten years by researchers in various fields including Statistical Mechanics, Anthropology, Structural Biology, Distributed Systems, Theoretical Computer Science, Robotics and Control theory has shown that there is a lot of commonality in

the structure of different networks – be it communication among a school of fish, pack of wolves, a group of jihadis, or an ad-hoc wireless network. The goal of the Network Sciences Division is to make use of this commonality, in a synergistic way, to address issues of importance to the Army. Networks of sensors, communication and computation nodes, and robots are pervasive throughout the Army and especially in Command, Control, Communications, Computing, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems. The Network Science Division identifies and addresses the Army's critical basic research problems in C4ISR where progress has been inhibited by a lack of novel concepts or fundamental knowledge. Research in this program has applications to a wide variety of developmental efforts and contributes to the solution of technology-related problems throughout the Army's Future Force operational goals.

The ARO supports and advances fundamental research and knowledge that focuses on the needs of the Army's effort to be net-centric. To accomplish this objective, the Division supports extramural basic research in the four areas of Communication and Human Networks, Intelligent Networks, Multi-Agent Network Control and Decision and Neuro-Sciences. The boundary between these programs is fluid and, thus, a research topic might fall in more than one area. In fact, research that will elucidate and define the common underpinning science that cuts across different types of networks is of particular interest. In many cases, there will be a close relationship to the Mathematical and Computer Sciences programs in the directorate.

10.1 Communication and Human Networks. This program is concerned with the application of the emerging network science to wireless communication networks and human social networks. In both of these areas, DoD and particularly Army unique problems will be investigated. For communications networks, tactical multi-hop wireless communications which lack fixed infrastructure will be investigated. For social networks, problems such as understanding adversarial networks with limited data and the effects of the human network on military decision making are example topics of interest. Also of interest is the interaction of the communications network with primarily the social network but also the information network.

New and existing methods in the areas of information theory, game theory, and graph theory need to be applied to these problems in order to find unique solutions.

10.1.1 Wireless Network Theory. Research is required in the broad area of wireless network science including fundamental limits, performance characterization, novel architectures, and high fidelity simulation. Metrics, fundamental limits, and performance need to be characterized for multi-hop wireless networks with mobility, node loss, and bursty traffic. New simulation techniques are necessary to allow for very large simulations without losing the fidelity at the physical layer that is necessary for realistic results.

10.1.2 Mobile Ad Hoc Networks. Networks serving Army needs must operate in highly dynamic environments with limited infrastructure support. Nodes in such networks often have only noisy local information and must operate in a decentralized fashion. New research approaches are needed to explicitly account for the lack of full network state information and the cost of coordination. New physical layer and network coding techniques capable of coping with

incomplete/mismatched network-state information are needed. Novel physical layer techniques, particularly those that have LPI/LPD/AJ characteristics are also of interest.

Army wireless networks require a high level of robustness and efficiency in uncertain environments. Cognitive communication and networking techniques are needed for the dynamic allocation of resources based on operation needs, traffic characteristics, dynamic topologies, interference conditions, and security considerations. Dynamic optimization and learning methods are needed to discover and capture communication and networking opportunities. Networking and sensing architectures for cognitive mobile ad hoc networks need to be developed with qualitative and quantitative performance measures. The impacts of mobility, fading, and multi-user interference need to be investigated.

Classical communication and information theory relies on ergodicity to mitigate effects of random phenomena such as noise, fading, traffic patterns, and user mobility. Wireless networks for the Army for future combat applications require efficient, reliable operations in the finite-time, finite-network, and finite-resource regime. In this context, new mathematical theory, design metrics, and methodologies are required across all layers of networks.

Networking in combat operations needs to cope with the presence of passive or active adversaries of various types. New signal processing, information theory, and networking theory methodologies are needed to provide reliable and efficient communications in the presence of various adversarial actions. There is a need to characterize fundamental tradeoffs among various conflicting objectives: between secrecy/anonymity vs. rate of communications vs. resource consumption, the need for rapid response and the requirement of authentication and security.

10.1.3 Sensor Networks. Providing energy efficient sensor networking under different operating conditions presents difficult technical challenges. New techniques are needed for sensor fusion using Shannon and non-Shannon information theoretic metrics for bandwidth and energy efficiency. Distributed synchronization methods with limited information exchange for varying network topology and heterogeneous delay requirements are needed. Research should investigate fundamental performance bounds and characterize the tradeoffs between conflicting metrics. Sensor networks will be deployed for sensing, actuation and control, and research must illuminate the controllability of these networks under challenging channel conditions.

10.1.4 Human Networks. Topology, dynamics, and information flow within human networks is of interest as well as interaction of communications and human networks. In particular, this program will leverage mathematical techniques utilized in network science to analyze other types of networks, such as network information theory, graph theory, game theory, data mining, and Markov chains, to analyze human networks.

Determining social network structure from heterogeneous data is of prime interest to this program. Data can be derived based on multiple forms of electronic contacts, such as email, phone calls, social networking sites, as well as face to face contacts. Complicating factors include very large networks, limited data per potential link, and distinguishing between important links and coincidental links.

An important question is to characterize how social networks facilitate such functions as aggregating information, propagating beliefs, imposing constraints, developing incentives, and conducting transactions. How do groups aggregate information over networks? How do information shocks get absorbed in the network or explode through the network? How can misinformation be contained? How does the network structure affect the efficiency of information propagation? Which networks are robust in aggregating information efficiently?

Another area of interest is the interaction of heterogeneous networks consisting of human and technological agents. How do human networks interact with technological networks? The working group concluded that the presence of human actors in the loop significantly changes the analysis and design of communication networks in the military applications. Important questions include: How do human networks behave in the presence of constraints imposed by the communication network? How do we design communication networks to achieve a global mission among the human actors which may be evolving in time as more information gets revealed and circumstances change? Interaction between human and communications networks need to be analyzed, such as the interaction of QoS communications goals with the requirements of the human network in a tactical scenario.

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10.2 Decision & Neuro-Sciences. The objective is to advance frontiers of mathematics and neuroscience to create new paradigms which improve decision making in highly complex, dynamic and uncertain environments. Two major thrusts include:

- Mathematical modeling of neural processes
- Stochastic optimization and modeling

10.2.1 Mathematical modeling of neural processes. This multi-disciplinary thrust seeks innovations to quantitatively model decision behaviors in neural-anatomical or other observable measures to explain how factors such as complexity, uncertainty, stressors, social and other dynamics affect decisions. The decision-making "algorithm" of the brain is not understood. Highly complex, dynamic, parallel and redundant neural spiking behaviors complicate identification and mapping of the neural network of the brain involved in decision making. Recent advances in neuroscience provide important foundations to understand factors affecting decision making. These include neuro-economics and trust research, relationships of neural processes in handling uncertainty, time constraints and other stressors.

Examples of research that could contribute to this thrust include:

- Empirical studies into physiological, psychological and cognitive modeling of decision making
- Jointly funded projects within the Life Sciences Division Neurosciences Program involving interdisciplinary work – mathematical and neuroscience -- into empirical studies of neural behaviors in decision making or higher cognitive functions, such as learning.

- Development of neuroscience studies to inform and identify new bio-inspired algorithms; natural neural "algorithms" which improve upon current artificial algorithms for optimization and modeling.

10.2.2 Stochastic Optimization and Modeling. This thrust addresses advances in mathematical algorithms to better address stochastic data properties common in:
Highly dynamic, heterogeneous and complex operational environments
Ill-conditioned and varying information such as in dynamic complex social contexts

Examples of research that could contribute to this thrust include:

- Modeling and simulation of contemporary environments (addressing adversarial strategies, classic terrain features, demographically-informed population information, as well as dynamic temporal information) with the objective of decision support
- Fundamental graph theory and network analysis in support of modeling social networks and other complex systems behaviors and processes
- Numerical optimization and modeling to include capabilities for stochastic behaviors; novel approaches which address more general conditions and distributions
- Bayesian and other evidential reasoning and fusion approaches to model wide ranging, perhaps real-time, and incomplete information
- Sequential dynamic decision making approaches
- New algorithms with provable or demonstrable improved performance bounds
- Game theoretical and simulation approaches applied to asymmetric warfare situations

This new program advances work in developing improved and robust models and algorithms taking into account multiple complex factors, including highly stochastic and dynamic behaviors.

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10.3 Intelligent Networks. The overall objective of the Intelligent Networks program is to augment human decision makers (both commanders and soldiers) with enhanced-embedded battlefield intelligence that will provide them with the necessary situational awareness, reconnaissance, and decision making tools to decisively defeat any future adversarial threats. This necessitates the development of intelligent tools that enhance human abilities by taking over mundane tasks. A complimentary aspect of the overall goal is the task of making autonomous systems intelligent. The challenge entails discovery of methods that facilitate the development of intelligent and autonomous systems that perceive their environment by means of sensing and through context, and the use of that information to generate intelligent, goal-directed, desired behaviors. This area of research poses unique challenges for the Army as it involves developing autonomous capability for mixed teams of air and ground vehicles that act to complement a soldier's capabilities. The focus is, thus, on developing a formalized mathematical, algorithmic, and practical understanding of intelligence that combines perception, control, knowledge representation, language processing and learning to facilitate the development of intelligent and autonomous systems and tools. Furthermore, the Intelligence Networks program aims to be glue that supports fundamental work in "intelligence" which can be utilized in other programs within

the Computer Sciences and Network Sciences divisions. Consequently, the following areas of research are the main thrusts of this program:

10.3.1 Integrated Intelligence. Sub-components for vision, knowledge representation, reasoning, and planning are integrated in a synergistic fashion to yield a sum that is more than its parts. Research of interest includes algorithmic methods for avoiding state explosion in combining various sub-components of intelligence, as well as cognitive and neuroscience inspired approaches to dovetail learning with control, planning, perception, etc.

10.3.2 Robust Reasoning Under Uncertainty. The ability to adapt or compensate, in reasoning, for the uncertainty inherent in real systems related to modeling error, sensing errors and noise, system failures, and changing dynamic environments, are important. Two further aspects of reasoning are reflection and transparency – the ability of autonomous systems and intelligent tools to explain the current state of the world, as they see it, and to be able to explain their internal state and their actions. The latter is especially important in systems that can learn and, thus, its behavior can change with time.

10.3.3 Socio-Cultural Reasoning. Development of appropriate mathematical tools to model and reason about societies and cultures, that brings together tools from Game Theory, Social Sciences and Knowledge Representation. Research of interest include, but is not limited to, development of Game Theory for security applications while accounting for bounded rationality, development of Game Theory based on data regarding cultural and adversarial groups, and Behavioral Game Theory that can explain intelligence in groups and societies.

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10.4 Multi-Agent Network Control. The Multi-Agent Network Control research program is concerned with developing novel mathematical abstractions and methods for the modeling and control of both individual agents as well as the collective behavior of large scale networks of heterogeneous multi-agent systems. In this regard, the term “agent” can span the biological, physical, and information and communication domain. Autonomy is central to program efforts as anticipated dynamics of the future battle space will require a greatly increased level of autonomy to enable the necessary mobility, sensor coverage, information flow, and responsiveness to support the military goals of information superiority, dominant maneuver, and precision engagement.

10.4.1 Nonlinear Agent Control and Perception. Many future systems of Army interest exhibit strongly or essentially nonlinear behavior or must operate in regimes where detailed modeling and computation is prohibitive or expensive. Of particular interest are new methods to merging the biological and cognitive sciences to enable new perception-based control methods that emphasize quality rather than quantity of measurements and information to guide control decisions in severe and uncertain environments. Further topics of interest in this thrust include adaptive, nonlinear, optimal, stochastic, embedded, and hybrid control; learning systems; non-conventional game theory; and intelligent decision-making. Accurate and efficient

computational procedures are sought, which provide solutions of intelligent control of time-sensitive applications in severe environments.

10.4.2 Control and Dynamics of Multi-agent Networks. The Army maintains keen interest in understanding the dynamics of networks across the basic sciences as well as the behavior of socio-economic interactions and mobile communication networks. This particular thrust emphasizes novel, scalable mathematical models and methods for controlling complex network dynamics as well as new scientific understanding of feedback architectures within high dimensional, hierarchically organized multi-agent systems. Such systems may be either synthetic, naturally occurring, or some combination thereof. Further topics include, but are not limited to: mathematical abstractions related to distributed system theory; metrics for system complexity, information content, flow, structure, swarming phenomena, design of emergent behavior for heterogeneous multi-agent systems, and information processing and data fusion for decision-making and distributed multi-agent theory.

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k. RESEARCH AREA 11: ARO SPECIAL PROGRAMS

11.1. SHORT-TERM INNOVATIVE RESEARCH (STIR) PROGRAM.

The objectives of the STIR program are to provide rapid, short-term investigations to assess the merit of innovative new concepts in basic research.

11.1.1. Eligibility. Research proposals are sought from educational institutions, nonprofit organizations, and commercial organizations. Prospective offerors of a STIR proposal are encouraged to contact the appropriate ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA, to ascertain the extent of interest in the specific research project.

11.1.2. Research Sought. Proposals in the amount of $50,000 or less are sought for research in the areas identified earlier in the ARO Research Areas of this BAA.

11.1.3. Proposal Preparation.

11.1.3.1. Organizations or institutions should submit proposals that are no more than twenty (20) pages in length, inclusive of the budget, transmittal letter, and attachments. Any proposal in excess of 20 pages will not be considered. No brochures or explanatory material should be submitted with the proposal.

11.1.3.2. Proposed research efforts must be "stand alone" and not predicated on the use of any facilities other than those under the direct control of the offeror. Research must be completed within nine (9) months of award of the agreement. **Extensions of the nine-month performance period will not be granted.**

11.1.3.3. The research proposal should follow the format set forth in Section II.D (Application and Submission Information) of this BAA. Limited rights data should be identified as an attachment to the proposal. Otherwise, it will be assumed that the proposal does not contain limited rights data.

11.1.3.4. No capital equipment may be purchased. Travel costs must not exceed $500. Report preparation costs must not exceed $100. Fee is not permitted under STIR Program awards. Indirect costs will not be reimbursed under STIR Program awards. Any applicable indirect costs must be borne by the offeror.

11.1.3.5. The principal investigator(s) should disclose and explain the relevance of the proposal to the research interests identified earlier in the ARO Research Areas of this BAA.

11.1.3.6. A brief, final technical report is required. Please note that your award document will reference Form 18, "Reporting Instructions," as found at http://www.arl.army.mil/www/default.cfm?page=29. You shall use these reporting instructions for format instructions only; the due date for receipt of a final technical report is thirty (30) days from completion of the award.

11.2. YOUNG INVESTIGATOR PROGRAM (YIP).

The objective of the YIP is to attract to Army research outstanding young university faculty members, to support their research, and to encourage their teaching and research careers. Young investigators meeting eligibility requirements may submit a YIP proposal. Outstanding YIP projects may be considered for a Presidential Early Career Award for Scientists and Engineers (PECASE). PECASE awards are the highest honor bestowed by the Army on outstanding scientists and engineers beginning their independent careers.

11.2.1. Eligibility. This program is open to U.S. citizens, Nationals, and resident aliens holding tenure-track positions at U.S. universities and colleges, who have held their graduate degrees (Ph.D. or equivalent) for fewer than five years at the time of application. Faculty at an institution of higher education which does not designate any faculty appointments as "tenure track" are eligible if that is so indicated in the proposal, and the supporting letter from the university states that the faculty member submitting the proposal will be considered for a permanent appointment.

11.2.2. Research Sought. Proposals are invited for research in areas described earlier in the ARO Research Areas. Proposals may be submitted at any time. As is the case for all other research programs, informal discussions with the cognizant ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA is strongly recommended before submission of a formal proposal. An award in each topic area is not guaranteed. YIP awards, not to exceed $50,000 per year for three years, will be made based on research proposals and supporting material.

11.2.3. Proposal Preparation.

11.2.3.1. An individual applying for a YIP award must submit a research proposal and a supporting letter, both through official university channels. Any resulting agreement will be

made to the institution, not to the investigator. The research proposal should follow the format set forth in Section II.D (Application and Submission Information) of this BAA.

Technical Point of Contact: Contact the relevant Program Manager

11.2.3.2. The supporting letter must be from the applicant's Department Chairperson, Dean, or other official who speaks for the university, and should address support for and commitment to the applicant. Strong university support for the applicant is essential. This support can include the applicant's nine-month academic salary, release time from administrative responsibilities, the purchase of equipment, support for the applicant's graduate students, waiver of indirect costs, departmental cost sharing, start-up funding, and so on. It must be clear that the university views the applicant as a truly outstanding, potential leading faculty member, and is making a long-term commitment to the application and the research.

11.2.4. Evaluation Factors. The evaluation factors to be used in determining which proposals are selected for funding are described in Section II.E (Application review information) of this BAA. In addition, proposals submitted for YIP funding will be evaluated based on a long-term commitment by the university to the applicant and the research. YIP proposals will be selected for award on a competitive basis after a peer scientific review.

11.2.5. Continued Support. Support under the YIP is limited to three years. Upon completion of the YIP, young investigators may apply and be considered for continued support in the areas identified earlier in the ARO Research Areas of this BAA. Decisions about continued funding outside the context of the YIP will be made following a peer scientific review, a review of ARO's research priorities, and the creativity and productivity demonstrated during the previous research program.

11.3. Presidential Early Career Award for Scientists and Engineers (PECASE).

11.3.1. An applicant may not directly apply for a PECASE award. Instead, once a year, ARO technical program managers will nominate PECASE candidates from among all ARO YIP and other eligible proposals and white papers (if any) received. The technical program manager will make the PECASE nomination based on strong endorsement of the YIP proposal by the external scientific reviewers and on the great potential shown by the investigator to contribute to science and to the mission of the Army.

11.3.2. Following nomination of a PECASE candidate, a supplemental PECASE proposal will be requested in which the candidate will indicate how PECASE funding would augment the YIP project. PECASE awards are not to exceed $200,000 per year for five years. Supporting information including letters of recommendation, detailed scientific biographical information, and a summary of past research accomplishments will be required in the PECASE proposal.

11.3.3. Complete PECASE proposal packages will be evaluated by external scientific reviewers. The proposals which demonstrate the greatest potential to contribute to science and to the mission of the Army will be rank ordered by an Army PECASE Evaluation Committee. The PECASE packages are evaluated based on (1) Publications, (2) Presentations, (3) Scientific

Leadership, (4) Mission Relevance of the research, (5) Community Outreach, (6) Department Commitment & Recommendation Letters, and (7) Scientific Quality of the research.

11.3.4 Continued Support. Support under PECASE is limited to five years. Upon completion of the PECASE project, young investigators may apply and be considered for continued support in the areas identified earlier in the ARO Research Areas of this BAA. Decisions about continued funding outside the context of PECASE will be made following a peer scientific review, a review of ARO's research priorities, and the creativity and productivity demonstrated during the previous research program.

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11.4. RESEARCH INSTRUMENTATION (RI) PROGRAM.

Research instrumentation is designed to improve the capabilities of U.S. universities to conduct research and educate scientists and engineers in areas important to national defense. Of the funds available to acquire ARO research described in this BAA, funds may be provided to purchase instrumentation in support of this research or in the development of new research capabilities.

11.4.1. Eligibility and Areas of Interest. It is highly recommended that potential offerors contact the appropriate ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA for advice and assistance before preparation of an instrumentation proposal.

11.4.2. Content of Request for Instrumentation. The request for instrumentation shall include:

11.4.2.1. A concise abstract (approximately 300 words) that describes the instrumentation requested and the research to be supported by that instrumentation.

11.4.2.2. A budget that addresses equipment to be purchased, cost per item, and total cost. Indicate the proposed source of the equipment and the name and telephone number of a contact at that source. The budget should indicate the amount of funds to be contributed by other sources toward the purchase of the instrumentation.

11.4.2.3. A description of how the proposed instrumentation will: (i) establish new research capabilities, (ii) contribute to research currently proposed to DOD, or (iii) enhance the quality of research currently being funded by ARO.

11.4.2.4. A description of how the proposed instrumentation will interface with or upgrade other research facilities and instrumentation now available.

11.4.2.5. A description of the amounts and sources of ongoing or proposed support for the research to be supported by the instrumentation.

11.5. DOD PROGRAMS.

11.5.1. Each year the Army Research Office, along with the Office of Naval Research (ONR) and the Air Force Office of Scientific Research (AFOSR), participates in two programs sponsored by the Office of the Assistant Secretary of Defense for Research and Engineering. These two programs, titled the Defense University Research Instrumentation Program (DURIP) and the Research and Educational Program (REP) for Historically Black Colleges and Universities/Minority Serving Institutions (HBCU/MI)are conducted under separate BAAs that are posted yearly on the ARO web site. For the purpose of these two programs, the areas of interest for submitting proposals are limited to Research Areas as identified earlier in the ARO Research Areas of this BAA. Offerors are reminded that these two BAAs have definitive closing dates for receipt of proposals (see each specific BAA for details). In addition, offerors must review the specific BAAs for eligibility considerations.

Solicitations are available on the ARO website under "Funding Opportunities" as well as the Grants.gov website. These solicitations will have a definite closing date for proposal submission, and offerors are advised to review the solicitations for eligibility considerations.

11.5.2. DEFENSE UNIVERSITY RESEARCH INSTRUMENTATION PROGRAM (DURIP). Research instrumentation is designed to improve the capabilities of U.S. universities to conduct research and educate scientists and engineers in areas important to national defense. Of the funds available to acquire research described earlier in the ARO Research Areas of this BAA, funds may be used only to purchase instrumentation in support of this research or in the development of new instrumentation in support of these research areas.

11.5.2.1. Eligibility and Areas of Interest. To be eligible for an instrumentation award, it is highly recommended that potential offerors contact the appropriate ARO Technical Point of Contact (TPOC/ Program Manager) identified earlier in the ARO Research Areas of this BAA for advice and assistance before preparation of an instrumentation proposal.

11.5.2.2 Content of Request for Instrumentation. The request for instrumentation shall include:

11.5.2.2.1. A concise abstract (approximately 300 words) that describes the instrumentation requested and the research to be supported by that instrumentation.

11.5.2.2.2 A budget that addresses equipment to be purchased, cost per item, and total cost. Indicate the proposed source of the equipment and the name and telephone number of a contact at that source. The budget should indicate the amount of funds to be contributed by other sources toward the purchase of the instrumentation.

11.5.2.2.3. A description of how the proposed instrumentation will: (i) establish new research capabilities, (ii) contribute to research currently proposed to DOD, or (iii) enhance the quality of research currently being funded by ARO.

11.5.2.2.4. A description of how the proposed instrumentation will interface with or upgrade other research facilities and instrumentation now available.

11.5.2.2.5. A description of the amounts and sources of ongoing or proposed support for the research to be supported by the instrumentation.

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11.5.3. Research and Educational Program (REP) for Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI).

The Army Research Office periodically issues solicitations for proposals from HBCUs and MIs under the policy and guidance of the Office of the Assistant Secretary of Defense for Research and Engineering (OASD(R&E)). The program aims to (a) enhance HBCU/MI programs and capabilities in scientific and engineering disciplines critical to the national security functions of the DoD, (b) encourage greater HBCU/MI participation in DoD programs and activities, (c) increase the number of graduates, including underrepresented minorities, in the fields of science, technology, engineering and/or mathematics (STEM), and (d) encourage research and educational collaborations.

Technical Point of Contact: Mr. Michael Caccuitto, michael.j.caccuitto.civ@mail.mil, (919) 549-4369

3. OTHER PROGRAMS

a. CONFERENCE AND SYMPOSIA GRANTS

1. Introduction. The Army supports conferences and symposia in special areas of science that bring experts together to discuss recent research or educational findings or to expose other researchers or advanced graduate students to new research and educational techniques. The Army encourages the convening in the United States of major international conferences, symposia, and assemblies of international alliances.

2. Eligibility. Notwithstanding the above, the Department of Defense (DOD) has imposed certain restrictions on the Army's co-sponsorship of scientific and technical conferences and symposia. Specifically, DOD Instruction 5410.20 prohibits co-sponsorship of conferences and symposia with commercial concerns. Scientific, technical, or professional organizations which qualify for tax exemption under the provision of 26 U.S.C. Sec. 501(c)(3) may receive conference and symposia grants. For questions regarding your organization's eligibility for a conference or symposia grant, please contact the ARO Legal Office at (919) 549-4292 or e-mail: edward.e.beauchamp.civ@mail.mil, or the ARL-Aberdeen Proving Ground Legal Office at (410) 278-6487 or e-mail: peggy.l.gieseking.civ@mail.mil.

3. Conference Support. Conference support proposals should be submitted a minimum of six (6) months prior to the date of the conference.

4. Technical Proposal Preparation. The technical portion of a proposal for support of a conference or symposium should include:

a. A one page or less summary indicating the objectives of the project.
b. The topics to be covered.
c. The location and probable date(s) and why the conference is considered appropriate at the time specified.
d. An explanation of how the conference will relate to the research interests of the Army and how it will contribute to the enhancement and improvement of scientific, engineering, and/or educational activities as outlined earlier in the ARO Research Areas of this BAA.
e. The name of chairperson(s)/principal investigator(s) and his/her biographical information.
f. A list of proposed participants and the methods of announcement or invitation.
g. A summary of how the results of the meeting will be disseminated.
h. A signed cover page.

5. Cost Proposal Preparation. The cost portion of the proposal should show:

a. Total project conference costs by major cost elements.
b. Anticipated sources of conference income and amount from each.
c. Anticipated use of funds requested.
d. A signed budget.

6. Participant Support. Funds provided cannot be used for payment to any federal government employee for support, subsistence, or services in connection with the proposed conference or symposium.

7. Cognizant ARO Technical Point of Contact (TPOC/ Program Manager). It is highly recommended that potential offerors contact the appropriate ARO TPOC/ Program Manager identified earlier in the ARO Research Areas of this BAA for advice and assistance before preparation of a conference/symposia proposal.

b. HISTORICALLY BLACK COLLEGES AND UNIVERSITIES AND MINORITY SERVING INSTITUTIONS (HBCU/MIs)

The Army has a long history of advocating and supporting research at HBCU/MIs. Through this solicitation, the Army Research Laboratory (ARL) and the Army Research Office (ARO) actively seek proposals from the HBCU/MI community in full and open competition with all offerors. Proposals may relate to any research topic described herein. In addition to single investigator research proposals, collaborative research proposals are also encouraged. Collaborations may be between HBCU/MIs and other institutions of higher education (not limited to HBCU/MIs) and/or industry partners.

The ARO encourages basic research proposals from HBCU/MIs in response to the ARO Research Areas of this BAA in full and open competition with all offerors. Included are special

emphasis programs such as Short-Term Innovative Research (STIR) and the Young Investigator Program (YIP), described in detail elsewhere in this announcement.

Through this solicitation, the ARO encourages basic research proposals from the HBCU/MI community in full and open competition with all offerors. Proposals may relate to any research topic described herein. In addition to single investigator basic research, collaborative research proposals are also of interest. Collaborations may be between HBCU/MIs and other institutions of higher education (not limited to HBCU/MIs) and/or industry partners.

In addition to the ARO basic research program, there are other special funding opportunities available to HBCUs/MIs through ARO. Research and educational programs and activities for HBCUs/MIs are established in accordance with Section 252 of the National Defense Authorization Act for Fiscal Year 2010 (enacted in 10 U.S.C. 2362) and the Department of Defense Appropriations Act, 2010. As noted above, the program is executed under policy and guidance of the Office of the Assistant Secretary of Defense for Research and Engineering (OASD(R&E)). Solicitations are issued annually and are available on the ARO website as well as through Grants.gov.

The program aims to (a) enhance HBCU/MI programs and capabilities in scientific and engineering disciplines critical to the national security functions of the DoD, (b) encourage greater participation by HBCU/MIs in DoD programs and activities, (c) increase the number of graduates, including underrepresented minorities, in the fields of science, technology, engineering and/or mathematics (STEM), and (d) encourage research and educational collaborations.

In addition, ARO may periodically release special DoD solicitations that target specific groups such as Tribal Colleges and Universities (TCUs). The DoD solicitations may offer one or more of the following components: research; instrumentation enhancement (for research and/or educational purposes); scholarships; fellowships; collaborative research; and centers of excellence.

Point of Contact for the ARO and DoD HBCU/MI programs is Mr. Michael Caccuitto, (919)549-4369; email: michael.j.caccuitto.civ@mail.mil.

Eligibility. Eligible institutions include:

a. institutions of higher education eligible for assistance under Title III or V of the Higher Education Act of 1965 (20 U.S.C. 1051 et seq.); or
b. an accredited postsecondary minority serving institutions.

These definitions encompass a large and diverse group of institutions. Enrollments, accreditation, and other factors may affect an institution's eligibility in any given year. Therefore, each institution must determine its eligibility based on these criteria. A current copy of minority certification or Title III or V certificate and accreditation documents must be included with each proposal.

c. Science, Technology, Engineering, and Mathematics (STEM) Army Educational Outreach Program (AEOP)

AEOP is comprised of Army-sponsored research, education, competitions, internships and practical experiences designed to engage and guide students and teachers in science, technology, engineering, and mathematics (STEM). More information about AEOP is available at www.usaeop.com. With available funding, the Army seeks to expand the reach and scope of the AEOP by considering ideas from the field for innovative STEM education programs that will fit into the AEOP portfolio and strengthen its mission of impacting the Nation's STEM literacy. Program emphasis may include, but is not limited to, reaching underrepresented or disadvantaged populations, reaching areas of the country not currently served by AEOP, supporting teachers' efforts to engage students, engage K-6 grade students in STEM activities.

Programs can apply a wide range of approaches including virtual education/resources, hands-on activities, development of classroom resources, novel partnerships with industry or academia, to name a few. Proposals should have a defined program evaluation plan to measure efficacy and collect/report participation data. The program also supports the development of methodologies (e.g., data collection, statistical methods, and research designs) that have the potential to help advance the DoD impact in STEM education outreach and/or the development of initiatives that aim to increase human capital in the management of STEM.

Technical Point of Contact: Ms. Ashley Wade, (919) 549-4205, e-mail: ashley.e.wade.civ@mail.mil.

d. High School Apprenticeship Program (HSAP)/Undergraduate Research Apprenticeship Program (URAP)

The HSAP funds the STEM apprenticeship of promising high school juniors and seniors to work in a university structured research environment under the direction of ARO sponsored principal investigators (PIs) serving as mentors. The URAP provides similar opportunities for Undergraduate students. Awards will be made as add-ons to research grants, MURIs, and cooperative agreements that have at least 12 months' period of performance remaining from the date of HSAP/URAP proposal submission.

The overall objectives of HSAP/URAP include: ensuring a high quality and high quantity STEM workforce in the U.S.; fostering student interest in STEM subject areas; facilitating follow-on student opportunities including university enrollment and DoD scholarships/internships; and ultimately exposing the apprentices to the attractive, meaningful, and challenging military and civilian career STEM opportunities.

Limited funding is available annually for Principal Investigators interested in participating in HSAP/URAP. PIs should submit a short proposal that clearly articulates the meaningful research that the apprentice will conduct along with the strategy for mentorship and facilitation of follow-on opportunities (e.g., university attendance, other research experiences, etc). Proposal should

include provisions to pay HSAP/URAP students a stipend equivalent to approximately $10 per hour; not to exceed 300 hours total. Proposal should be limited to two students per PI.

Technical Point of Contact: Ms. Ashley Wade, (919) 549-4205, e-mail: ashley.e.wade.civ@mail.mil.

B. Award Information

The ARL, to include ARO, have the authority to award a variety of instruments. The ARL/ARO reserves the right to use the type of instrument most appropriate for the effort proposed. Offerors should familiarize themselves with these instrument types and the applicable regulations before submitting a proposal. Following are brief descriptions of the possible award instruments.

1. Procurement Contract. A legal instrument, which, consistent with 31 U.S.C. 6303, reflects a relationship between the Federal Government and a State, a local government, or other recipient when the principal purpose of the instrument is to acquire property or services for the direct benefit or use of the Federal Government.

2. Grant - A legal instrument that, consistent with 31 U.S.C. 6304, is used to enter into a relationship:

   a. The principal purpose of which is to transfer a thing of value to the recipient to carry out a public purpose of support or stimulation authorized by a law or the United States, rather than to acquire property or services for the DOD's direct benefit or use.

   b. In which substantial involvement is not expected between the DOD and the recipient when carrying out the activity contemplated by the grant.

   c. No fee or profit is allowed.

3. Cooperative Agreement - A legal instrument which, consistent with 31 U.S.C. 6305, is used to enter into the same kind of relationship as a grant (see definition "grant"), except that substantial involvement is expected between the DOD and the recipient when carrying out the activity contemplated by the cooperative agreement. The term does not include "cooperative research and development agreements" as defined in 15 U.S.C. 3710a. No fee or profit is allowed.

   Grants and cooperative agreements are governed by the following regulations:

   a. 2 CFR Part 220, "Cost Principles for Educational Institutions" (Formerly OMB Circular A-21)

   b. 2 CFR Part 225, "Cost Principles for State, Local and Indian Tribal Governments" (Formerly OMB Circular A-87)

c. OMB Circular A-102, "Uniform Administrative Requirements for Grants and Cooperative Agreements with State and Local Governments"

d. 2 CFR 215, "Uniform Administrative Requirements for Grants and Agreements with Institutions of Higher Education, Hospitals, and Other Non-Profit Organizations" (Formerly OMB Circular A-110)

e. 2 CFR Part 230, "Cost Principles for Non-Profit Organizations" (Formerly OMB Circular A-122)

f. OMB Circular A-133, "Audits of States, Local Governments, and Non-Profit Organizations"

g. DOD Grant and Agreement Regulations (DODGARs), DOD 3210.6-R

Copies of OMB regulations may be obtained from:

Executive Office of the President
Publications Service
New Executive Office Building
725 17th Street, N.W., Room 2200
Washington, DC 20503

Telephone: (202) 395-7332
FAX Requests: (202) 395-9068
http://www.whitehouse.gov/OMB/grants

An electronic copy of the DODGARs may be found at
http://www.dtic.mil/whs/directives/corres/html/321006r.htm

4. Technology Investment Agreement (TIA) Assistance Transaction other than a Grant or Cooperative Agreement (see DoDGARs Part 37). A legal instrument, consistent with 10 U.S.C. 2371, which may be used when the use of a contract, grant, or cooperative agreement is not feasible or appropriate for basic, applied, and advanced research projects. The research covered under a TIA shall not be duplicative of research being conducted under an existing DOD program. To the maximum extent practicable, TIA's shall provide for a 50/50 cost share between the government and the offeror. An offeror's cost share may take the form of cash, independent research and development (IR&D), foregone intellectual property rights, equipment, or access to unique facilities, as well as others. Due to the extent of cost share, and the fact that an other transaction does not qualify as a "funding agreement" as defined at 37 CFR 401.2(a), the intellectual property provisions of a TIA can be negotiated to provide expanded protection to an offeror's intellectual property. No fee or profit is allowed on other transactions.

5. Other Transaction for Prototype (OTA). A legal instrument, consistent with 10 U.S.C. 2371 (as supplemented by Section 845 of Public Law 104-201 and Section 804 of Public Law 104-201), which may be used when the use of a contract, grant, or cooperative agreement is not feasible or appropriate for prototype projects directly relevant to weapons or weapon systems proposed to be acquired or developed by the DOD. The effort covered under an other transaction for prototype shall not be duplicative of effort being conducted under an existing

DOD program (please refer to the "Other Transactions" OT Guide for Prototype Projects at www.acq.osd.mil/dpap/Docs/otguide.doc).

Unsuccessful Proposal Disposition. Unless noted in an offeror's proposal to the contrary, unsuccessful proposals will be retained for six (6) months from declination and then properly destroyed.

C. Eligibility Information

1. Eligible Applicants:

Degree-granting universities, nonprofit organizations, or industrial concerns may submit proposals. Proposals are encouraged from Historically Black Colleges and Universities (as determined by the Secretary of Education to meet requirements of Title III of the Higher Education Act of 1965, as amended (20 U.S.C. § 1061)) and from Minority Serving Institutions defined as institutions "whose enrollment of a single minority or a combination of minorities…exceeds 50 percent of the total enrollment." [20 U.S.C. § 1067k(3) and 10 U.S.C. § 2323(a)(1)(C)].

2. Cost Sharing or Matching:

There is no required cost sharing, matching, or cost participation to be eligible under this BAA. Exceptions to this may exist if the offeror is proposing the use of a TIA or an OTA as an award instrument.

3. Duns and Bradstreet Universal Numbering System (DUNS) Number and Central Contractor Registrations (CCR):

Each applicant (unless the applicant is an individual or Federal agency that is exempt from those requirements under 2 CFR 25.110(b) or (c), or has an exception approved by the agency under 2 CFR 25.110(d)) is required to: (i) Be registered in the CCR prior to submitting its application; (ii) provide a valid DUNS number in its application; and (iii) continue to maintain an active CCR registration with current information at all times during which it has an active Federal award or an application or plan under consideration by an agency. An award will not be made to an applicant until the applicant has complied with all applicable DUNS and CCR requirements.

4. Other:

Foreign owned, controlled, or influenced firms are advised that security restrictions may apply that could preclude their participation in these efforts. Before preparing a proposal, such firms are requested to contact the ARL Security and Counterintelligence Branch (301) 394-4166 concerning their eligibility. Pursuant to the policy of FAR 35.017 and supplements, selected Federally Funded Research and Development Centers may propose under this BAA.

D. Application and Submission Information

1. Address to View Broad Agency Announcement

This BAA may be accessed from www.grants.gov, www.fbo.gov , and the ARL website http://www.arl.army.mil/www/default.cfm?page=8.

2. Content and Form of Application Submission

Section 1 - General Information:

Preliminary Inquires: The ARL and ARO receive several hundred research proposals annually. Because of financial constraints, we are able to provide support for only a limited number of the proposals received. We realize that the preparation of a research proposal often represents a substantial investment of time and effort by the offeror. Therefore, in an attempt to minimize this burden, we strongly encourage organizations and individuals interested in submitting research proposals to make preliminary inquiries as to the general need for the type of research effort contemplated, before expending extensive effort in preparing a detailed research proposal or submitting proprietary information. The TPOCs' names, telephone numbers, and e-mail addresses are listed immediately after each research area of interest and they should be contacted as appropriate prior to the submission of whitepapers or formal proposals.

Classified Submissions: Classified proposals are not expected. However, in an unusual circumstance where an offeror believes a proposal has the potential to be classified, contact the corresponding security office. For ARL Core Competencies contact (301) 394-4166 and for the ARO Research Areas contact (919) 549-4356 prior to the proposal's submission.

Use of Color in Proposals: All proposals received shall be stored as electronic images. Electronic color images require a significantly larger amount of storage space than black-and-white images. As a result, offerors' use of color in proposals should be minimal and used only when necessary for details. Do not use color if it is not necessary.

Post Employment Conflict of Interest: There are certain post employment restrictions on former federal officers and employees, including special government employees (Section 207 of Title 18, U.S.C.). If a prospective offeror believes a conflict of interest may exist, the situation should be discussed with ARL legal personnel (ARO: Mr. Ed Beauchamp edward.e.beauchamp.civ@mail.mil or ARL: Ms. Peggy Gieseking at peggy.l.gieseking.civ@mail.mil) prior to expending time and effort in preparing a proposal.

Statement of Disclosure Preference: Please complete Form 52 or 52A stating your preference for release of information contained in your proposal. Copies of these forms are available at http://www.arl.army.mil/www/default.cfm?Action=29&Page=218#baaforms.

Equipment: Normally, title to equipment or other tangible property purchased with Government funds vests with nonprofit institutions of higher education or with nonprofit research organizations if vesting will facilitate scientific research performed for the Government. Commercial organizations are expected to possess the necessary plant and equipment to conduct the proposed research. Deviations may be made on a case-by-case basis.

Section 2 – The Application Process

The application process is in three stages as follows:

Stage 1- Verify the accuracy of your Dun & Bradstreet (D&B) registration at the D&B website http://fedgov.dnb.com/webform before registering with the Central Contractor Registration (CCR) at http://www.ccr.gov. Prospective offerors must be registered in CCR prior to award. The CCR obtains Legal Business Name, Doing Business Name (DBA), Physical Address, and Postal Code/ Zip+4 data fields from D&B: If corrections are required, registrants will not be able to enter/modify these fields in CCR; they will be pre-populated using D&B Data Universal Numbering System (DUNS) record data. When D&B confirms the correction has been made, the registrant must then re-visit ccr.gov and click a "yes"" D&B's changes. Only at this point will the D&B data be accepted into the CCR record. Allow two (2) business days for D&B to send the modified data to CCR.

Stage 2 - Prospective proposers are requested to submit white papers prior to the submission of a complete, more detailed proposal. The purpose of white papers is to minimize the labor and cost associated with the production of detailed proposals that have very little chance of being selected for funding. Based on assessment of the white papers, feedback will be provided to the proposers to encourage or discourage them to or from submitting full proposals. White papers should present the effort in sufficient detail to allow evaluation of the concept's technical merit and its potential contributions of the effort to the Army mission. Due to Government budget uncertainties, no specific dollars have been reserved for awards under this BAA.

Stage 3 - Interested offerors are required to submit full proposals. All proposals submitted under the terms and conditions cited in this BAA will be reviewed regardless of the feedback on, or lack of, a white paper.

All proposals for Assistance Instruments must be submitted electronically through Grants.gov in a Portable Document Format (.PDF). Proposals for Contract may be submitted via either Grants.gov or email to: usarmy.rtp.aro.mbx.baa@mail.mil. Requests for waiver of electronic submission may be submitted via e-mail to: usarmy.rtp.aro.mbx.baa@mail.mil or regular mail:

Army Research Office
ATTN: RDRL-RO (Proposal Processing)
P.O. Box 12211
RTP, NC 27709-2211

All required forms for proposals may be downloaded from the ARO web site at http://www.arl.army.mil/www/default.cfm?page=29 under "For the Researcher" (Forms, ARO BAA Forms).

Section 3: White Paper Preparation

1. White papers should focus on describing details of the proposed research, including how it is innovative and how it could substantially increase the scientific state of the art. Army relevance, and potential impact should also be described.

2. White papers are limited to five (5) pages plus the cover page and a one-page addendum as discussed below. Evaluators will be advised that they are only required to review the white paper cover page and up to five pages and the addendum.

3. Combine all files and forms into a single PDF before submitting.

TECHNICAL INFORMATION:

1. A detailed discussion of the effort's scientific research objective, approach, relationship to similar research, and level of effort shall be submitted. Also include the nature and extent of the anticipated results and, if known, the manner in which the work will contribute to the accomplishment of Army's mission and how this would be demonstrated.

2. The type of support, if any, that the offeror requests of the Government, such as facilities, equipment, demonstration sites, test ranges, software, personnel or materials, shall be identified as government furnished equipment (GFE), government furnished information (GFI), government furnished property (GFP), or government furnished data (GFD). Offerors shall indicate any Government coordination that may be required for obtaining equipment or facilities necessary to perform any simulations or exercises that would demonstrate the proposed capability.

3. As an addendum to the white paper, include biographical sketches (one page) of the key personnel who will perform the research, highlighting their qualifications and experience.

4. The cost portion of the white paper shall contain a brief cost estimate revealing all the component parts of the proposal, including research hours, burden, material costs, travel, etc.

RESTRICTIVE MARKINGS ON WHITE PAPERS:

1. Any proprietary data that the offeror intends to be used only by the Government for evaluation purchases must be identified. The offeror must also identify any scientific data contained in the white paper that is to be treated by the Government as limited rights

data. In the absence of such identification, the Government will assume to have unlimited rights to all scientific data in the white paper. Records or data bearing a restrictive legend may be included in the white paper. It is the intent of the Army to treat all white papers as privileged information before the award and to disclose their contents only for the purpose of evaluation.

2. The offerors are cautioned, however, that portions of the white papers may be subject to release under terms of the Freedom of Information Act, 5 U.S.C. 552, as amended.

EVALUATION AND DISPOSITION OF WHITE PAPERS:

1. Evaluation Process: Offerors are advised that invitations for complete proposals will be made based on the initial white paper submission and the availability of funding. As stated above, the white paper will be evaluated for the concept's scientific merit and potential contributions of the effort to the Army mission. Offerors whose white papers are evaluated as having significant scientific merit may be invited to submit a complete detailed proposal. Care must be exercised to ensure that classified, sensitive, critical technologies are not included. If such information is required, appropriate restrictive markings and procedures should be applied.

2. Disposition Process: After completion of the evaluation, the offeror will be notified in writing of the results.

Section 4: White Paper Submission

All White Papers must be submitted electronically and should be emailed directly to the Technical Point of Contact. Include the BAA number W911NF-12-R-0011 in the email subject line.

White papers submitted via email must be in the following format but do not require any special forms:

- Single PDF formatted file as an email attachment
- Page Size: 8 ½ x 11 inches
- Margins – 1 inch
- Spacing – single
- Font – Times New Roman, 12 point

Section 5: Preparation of Complete Research Proposals

COVER PAGE ARO FORM 51 for Contract proposals submitted by email. The Form SF 424 (R&R) is for all proposals submitted through Grants.gov (Assistance Instruments must submit through Grants.gov):

1. A Cover Page is required. Proposals will not be processed without either: (1) a signed Cover Page, ARO Form 51, or (2) an SF 424 R & R Form. More information regarding the Cover Page can be found in Section 6.

2. Should the project be carried out at a branch campus or other component of the submitting organization, that branch campus or component should be identified in the space provided (Block 11 on the ARO Form 51 and Block 12 on the SF424 R&R).

3. The title of the proposed project should be brief, scientifically representative, intelligible to a scientifically literate reader, and suitable for use in the public domain.

4. The proposed duration for which support is requested should be consistent with the nature and complexity of the proposed activity. For Core Competencies listed at Section II, A, 1, offerors shall discuss the preferred performance period with the TPOC. For Research Areas listed at Section II, A, 2, the ARO normally awards research agreements for periods up to three (3) years (1 basic year of performance with two 1-year options). Nevertheless, the federal awarding agency reserves the right to make awards with shorter or longer periods of performance.

5. Specification of a desired starting date for the project is important and helpful however, requested effective dates cannot be guaranteed.

6. Pursuant to 31 U.S.C. 7701, as amended by the Debt Collection Improvement Act of 1996 [Section 31001(I)(1), Public Law 104-134], federal agencies shall obtain each awardees' Taxpayer Identification Number (TIN). This number may be the Employer Identification Number for a business or non-profit entity or the Social Security Number for an individual. The TIN is being obtained for purposes of collecting and reporting on any delinquent amounts that may arise out of an awardees' relationship with the Government.

7. Offerors shall provide their organization's Data Universal Numbering System (DUNS) number. The DUNS number is a nine-digit number assigned by Dun and Bradstreet Information Services.

8. Offerors shall provide their assigned Commercial and Government Entity (CAGE) Code. The CAGE Code is a 5-character code assigned and maintained by the Defense Logistics Service Center (DLSC) to identify a commercial plant or establishment.

TABLE OF CONTENTS:

Use the following Format for the PROPOSAL TABLE OF CONTENTS

Forms are available at
http://www.arl.army.mil/www/default.cfm?page=218#forms

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This format applies to proposals submitted via email and via Grants.gov. Offerors' proposals should show the location of each section of the proposal, as well as major subdivisions of the project description.

STATEMENT OF DISCLOSURE PREFERENCE (FORM 52 OR 52A): Complete and sign ARO Form 52 (Industrial Contractors) or ARO Form 52A (Educational and Nonprofit Organizations).

PROJECT ABSTRACT:

1. The Project Abstract shall include a concise statement of work and basic approaches to be used in the proposed effort. The abstract should include a statement of scientific objectives, methods to be employed, and the significance of the proposed effort to the advancement of knowledge.

2. The abstract should be no longer than one (1) page and be in a form suitable for release under the Freedom of Information Act, 5 U.S.C. 552, as amended. The abstract should indicate the effort intended for each 12-month period of research, where applicable.

TECHNICAL PROPOSAL (PROJECT DESCRIPTION): The technical portion of the proposal shall contain the following:

1. A complete discussion stating the background and objectives of the proposed work, the scientific approaches to be considered, the relationship to competing or related research, and the level of effort to be employed. Include also the nature and extent of the anticipated results and how they will significantly advance the scientific state-of-the-art. Also, if known, include the manner in which the work will contribute to the accomplishment of the Army's mission. Ensure the proposal identifies any scientific uncertainties and describes specific approaches for the resolution of the uncertainties.

2. A brief description of your organization. If the offeror has extensive government contracting experience and has previously provided the information to the ARL, the information need not be provided again. A statement setting forth this condition should be made.
3. The names of other federal, state, local agencies, or other parties receiving the proposal and/or funding the proposed effort. If none, so state. Concurrent or later submission of the proposal to other organizations will not prejudice its review by the ARL if we are kept informed of the situation.

4. A statement regarding possible impact, if any, of the proposed effort on the environment considering as a minimum its effect upon water, atmosphere, natural resources, human resources, and any other values.

5. The offeror shall provide a statement regarding the use of Class I and Class II ozone-depleting substances. Ozone-depleting substances mean any substance designated as Class I by EPA, including but not limited chlorofluorocarbons, halons, carbon tetrachloride, and methyl chloroform and any substance designated as Class II by EPA, including but not limited to hydrochlorofluorocarbons. See 40 C.F.R. Part 82 for detailed information. If Class I or II substances are to be utilized, a list shall be provided as part of the offeror's proposal. If none, so state.

6. The type of support, if any, requested (e.g., facilities, equipment, and materials).

BIOGRAPHICAL SKETCHES:

1. This Section shall contain the biographical sketches for senior personnel only.

    a. Primary Principal Investigator: The “Primary” PI provides a single or initial point of communication between the sponsoring agency(s) and the awardee organization(s) about scientific matters. If not otherwise designated, the first PI listed will serve as the “Primary” PI. This individual can be changed with notification of the agency. The sponsoring agency(s) does not infer any additional scientific stature to this role among collaborating investigators.

    b. Co-Principal Investigators: The individual(s) a research organization designates as having an appropriate level of authority and responsibility for the proper conduct of the research and submission of required reports to the agency. When an organization

designates more than one PI, it identifies them as individuals who share the authority and responsibility for leading and directing the research, intellectually and logistically. The sponsoring agency(s) does not infer any distinction in scientific stature among multiple PIs.

2. The following information is required:

   a. Relevant experience and employment history including a description of any prior Federal employment within one year preceding the date of proposal submission.

   b. List of up to five (5) publications most closely related to the proposed project and up to five (5) other significant publications, including those being printed. Patents, copyrights, or software systems developed may be substituted for publications.

   c. List of persons, other than those cited in the publications list, who have collaborated on a project or a book, article, report or paper within the last four (4) years. Include pending publications and submissions. Otherwise, state "None."

   d. Names of each investigator's own graduate or post graduate advisors and advisees. The information provided in "c" and "d" is used to help identify potential conflicts or bias in the selection of reviewers.

3. For the personnel categories of postdoctoral associates, other professionals, and students (research assistants), the proposal may include information on exceptional qualifications of these individuals that merit consideration in the evaluation of the proposal.

4. The biographical sketches are limited to three (3) pages per investigator and other individuals that merit consideration.

BIBLIOGRAPHY: A bibliography of pertinent literature is required. Citations must be complete (including full name of author(s), title, and location in the literature).

CURRENT AND PENDING SUPPORT:

1. All project support from whatever source must be listed. The list must include all projects requiring a portion of the principal investigator's and other senior personnel's time, even if they receive no salary support from the project(s).

2. The information should include, as a minimum: (i) the project/proposal title and brief description, (ii) the name and location of the organization or agency presently funding the work or requested to fund such work, (iii) the award amount or annual dollar volume of the effort, (iv) the period of performance, and (v) a breakdown of the time required of the principal investigator and/or other senior personnel.

FACILITIES, EQUIPMENT, AND OTHER RESOURCES: The offeror should include in the proposal a listing of facilities, equipment, and other resources already available to perform the research proposed.

BUDGET PROPOSAL (including DD Form 1861):

1. Each proposal must contain a budget for each year of support requested and a cumulative budget for the full term of requested support. The budget form (Form 99) may be reproduced as needed. Locally produced versions may be used, but you may not make substitutions in prescribed budget categories nor alter or rearrange the cost categories as they appear on the form. The proposal may request funds under any of the categories listed so long as the item is considered necessary to perform the proposed work and is not precluded by applicable cost principles. In addition to the forms, the budget proposal should include no more than five (5) pages of budget justification for each year.

2. A signed summary budget page must be included. The documentation pages should be titled "Budget Explanation Page" and numbered chronologically starting with the budget form. The need for each item should be explained clearly.

3. All cost data must be current and complete. Costs proposed must conform to the following principles and procedures:

   Educational Institutions: 2 CFR Part 220 (formerly OMB Circular A-21)
   Nonprofit Organizations: 2 CFR Part 230 (formerly OMB Circular A-122*)
   Commercial Organizations: FAR Part 31, DFARS Part 231, FAR Subsection 15.403-5, and DFARS Subsection 215.403-5.

*For those nonprofit organizations specifically exempt from the provisions of 2 CFR Part 230, FAR Part 31 and DFARS Part 231 shall apply.

4. Sample itemized budgets and the information they must include for a contract and for grants and cooperative agreements can be found at Section II. H. (Other Information). Before award it must be established that an approved accounting system and financial management system exist.

APPENDICES: Some situations require that special information and supporting documents be included in the proposal before funding can be approved. Such information and documentation should be included by appendix to the proposal.

Section 6: Submission of Complete Research Proposals

Proposals must be submitted through the offeror's organizational office having responsibility for Government business relations. All signatures must be that of an official authorized to commit the organization in business and financial affairs.

Proposals must be submitted electronically using one of the two following formats. The content will remain the same whether using email or Grants.gov.

EMAIL SUBMISSION (for Contracts only)

a. Contracts may be E-mailed directly to usarmy.rtp.aro.mbx.baa@mail.mil. Do not email full proposals to the TPOC. All e-mailed proposals must contain the information outlined in Section II, D, 2 (Section 5), entitled "Table of Contents" including the electronic forms as follows: (1) ARO Form 51, Proposal Cover Page; (2) ARO Form 99, Summary Proposal Budget or equivalent, (3) ARO Current and Pending Support (unnumbered form), and (4) ARO Form 52 or ARO Form 52a. These forms may be accessed at http://www.arl.army.mil/www/default.cfm?page=218#forms under BAA Forms. The fillable PDF forms may be saved to a working directory on a computer and opened and filled in using the latest compatible Adobe Reader software application found at this Grants.Gov hot-link: http://www07.grants.gov/help/download_software.jsp#adobe811.

b. All forms requiring signature must be completed, printed, signed, and scanned into a PDF document. All documents must be combined into a single PDF formatted file to be attached to the e-mail.

c. Proposal documents (excluding required forms) must use the following format:
- Page Size – 8 ½ x 11 inches
- Margins – 1 inch
- Spacing – single
- Font – Times New Roman, 12 point

GRANTS.GOV SUBMISSION (For all Assistance Instruments. Contracts may be submitted via Grants.gov or via e-mail submission.)

1. Grants.gov Registration (See Section 7 below) must be accomplished prior to application through this process. Note- All web links referenced in this section and Section 7 are current as of 15 May 2012, but are subject to change by grants.gov and may not be updated here.

2. Specific forms are required for submission of a proposal. The forms are contained in the Application Package available through the Grants.gov application process. To access these materials, go to http://www.grants.gov, select "Apply for Grants," and then select "Download Application Package." A Grant Application Package and Application Instructions are available for download through the Grants.Gov Apply portal under CFDA Number 12.431/Funding Opportunity Number W911NF-12-R-0011. The following documents are mandatory: (1) Application for Federal Assistance (Research and Related) (SF 424 (R&R)), and (2) Attachments form.

(a) The SF 424 (R&R) form is to be used as the cover page for all proposals. Authorized Organization Representative (AOR) usernames and passwords serve as "electronic signatures" when your organization submits applications through Grants.gov. By using

the SF 424 (R&R), proposers are providing the certification required by 32 CFR Part 28 regarding lobbying . The SF 424 (R&R) must be fully completed. Block 11, "Descriptive Title of Applicant's Project," must reference the research topic area being addressed in the effort by identifying the specific paragraph from Section II, A 1 (ARL) or Section II, A, 2 (ARO).

(b) The Attachments form must contain the information outlined in Section II, D, 2 (Section 5), entitled "Table of Contents" of this BAA including three electronic forms as follows: (1) ARO Form 51, Proposal Cover Page; (2) ARO Form 99, Summary Proposal Budget; and (3) ARO Current and Pending Support (unnumbered form). These forms may be accessed at http://www.arl.army.mil/www/default.cfm?page=218#forms. The fillable PDF forms may be saved to a working directory on a computer and opened and filled in using the latest compatible Adobe Reader software application found at this Grants.Gov hot-link: http://www07.grants.gov/help/download_software.jsp#adobe811.

(c) All documents must be combined into a single PDF formatted file titled "W911NF-12-R-0011" Proposal" and uploaded into the mandatory Attachments form.

(d) The training demonstration at http://www07.grants.gov/assets/CompletingaGrants.govApplication.html will assist AORs in the application process. Remember that you must open and complete the Application for Federal Assistance (Research and Related) (SF 424 (R&R)) first, as this form will automatically populate data fields in other forms. If you encounter any problems, contact customer support at 1-800-518-4726 or at support@grants.gov. If you forget your user name or password, follow the instructions provided in the Credential Provider tutorial. Tutorials may be printed by right-clicking on the tutorial and selecting "Print".

(e) As it is possible for grants.gov to reject the proposal during this process, it is strongly recommended that proposals be uploaded at least two days before any deadlines established in the BAA so that they will not be received late and be ineligible for award consideration. It is also recommended to start uploading proposals at least two days before the deadline to plan ahead for any potential technical and/or input problems involving the applicant's own equipment.

Section 7: Grants.Gov Registration

Registration. Each organization that desires to submit applications via Grants.Gov must complete a one-time registration. There are several one-time actions your organization must complete in order to submit applications through Grants.gov (e.g., obtain a Dun and Bradstreet Data Universal Numbering System (DUNS) number, register with the Central Contract Registry (CCR), register with the credential provider, register with Grants.gov and obtain approval for an Authorized Organization Representative (AOR) to submit applications on behalf of the organization). To registered please see http://www07.grants.gov/applicants/get_registered.jsp.

Please note the registration process for an Organization or an Individual can take between three to five business days or as long as four weeks if all steps are not completed in a timely manner.

Questions relating to the registration process, system requirements, how an application form works, or the submittal process should be directed to Grants.gov at 1-800-518-4726 or support@grants.gov.

3. Submission Dates and Times:

White Papers and Proposals:
White papers and proposals will be considered through the methods noted previously until and including 31 March 2017.

4. Intergovernmental Review

Not Applicable

5. Funding Restrictions:

There are no funding restrictions associated with this BAA.

6. Other Submission Requirements:

Information To Be Requested From Successful Offerors- Offerors whose proposals are accepted for funding will be contacted before award to provide additional information required for award. The required information is normally limited to clarifying budget explanations, representations, certifications, and some technical aspects.

For Contracts Only- Performance Work Statements (PWS)- prior to award the Contracting Officer may request that the contractor submit a PWS for the effort to be performed, which will be incorporated into the contract at the time of award.

E. Application Review Information:

1. Criteria:

Proposals submitted in response to this BAA will be evaluated using the factors listed below (in descending order of importance):

a. The overall scientific and/or technical merits of the proposal.

b. The potential contributions of the effort to the Army mission and the extent to which the research effort will contribute to balancing the overall ARL/ARO research program.

c. The offeror's capabilities, related experience, facilities, techniques, or unique combinations of these, which are integral factors for achieving the proposed objectives.

d. The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or other key personnel who are critical to achievement of the proposed objectives.

e. The offeror's record of past performance.

f. The reasonableness and realism of proposed costs and fee.

2. Review and Selection Process:

a. Upon receipt of a proposal, the ARL/ARO staff will perform an initial review of its scientific merit and potential contribution to the Army mission and also determine if funds are expected to be available for the effort. Proposals not considered having sufficient scientific merit or relevance to the Army's needs or those in areas for which funds are not expected to be available may be declined without further review.

b. All proposals are treated as privileged information prior to award and the contents are disclosed only for the purpose of evaluation. Proposals not declined as a result of an initial review will be subject to a peer review by highly qualified scientists. While the offeror may restrict the evaluation to scientists from within the Government, to do so may prevent review of the proposal by those most qualified in the field of research covered by the proposal. The offeror must indicate on the appropriate proposal form (Form 52 or 52A) any limitation to be placed on disclosure of information contained in the proposal.

c. Each proposal will be evaluated based on all the evaluation criteria rather than against other proposals for research in the same general area.

3. Recipient Qualification

For CONTRACT Proposals:

The Federal Awardee Performance and Integrity Information System (FAPIIS) will be checked prior to making an award. The web address is: https://www.fapiis.gov/fapiis/govt/fapiispubaccessmain.jsp. The applicant representing the entity may comment in this system on any information about itself that a Federal Government Official entered. The information in FAPIIS will be used in making a judgment about the entity's integrity, business ethics, and record of performance under Federal awards that may affect the official's determination that the applicant is qualified to receive an award.

F. Award Administration Information:

1. Award Notices:

Offerors whose proposals are recommended for award will be contacted by a Contract/Grant Specialist to discuss any additional information required for award. This may include representations and certifications, revised budgets or budget explanations, certificate of current cost or pricing data, subcontracting plan for small businesses, and other information as applicable to the proposed award. The anticipated award start date will be determined at this time. The appropriate award document, when signed by the Government Contracting/Grants Officer is the authorizing award document.

2. Administrative and National Policy Requirements:

a. Required Certifications

For CONTRACT Proposals:

Certifications Required for Contract Awards. Certifications and representations shall be completed by successful offerors prior to award. Federal Acquisition Regulation (FAR) Online Representations and Certifications Application (ORCA) is at website http://orca.bpn.gov. Defense FAR Supplement and contract specific certification packages will be provided to the contractor for completion prior to award.

For GRANT and COOPERATIVE AGREEMENT Proposals:

Grant awards greater than $100,000 require a certification of compliance with a national policy mandate concerning lobbying. Statutes and Government-wide regulations require the certification to be submitted prior to award. The certification is set forth at Appendix A to 32 CFR 28 regarding lobbying. When submitting your grant through Grants.gov, by completing blocks 18 and 19 of the Standard Form 424 Research and Related (R&R) Form, the grant applicant is providing the certification on lobbying required by 32 CFR Part 28, otherwise a signed copy by the authorized representative must be provided.
Below is the required certification:

1. CERTIFICATION AT APPENDIX A TO 32 CFR PART 28 REGARDING LOBBYING:

Certification for Contracts, Grants, Loans, and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of an agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making

of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by Section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

b. Policy Requirements

1) Protection of Human Subjects. Assistance Instruments Only. All research involving human subjects must be conducted in accordance with 32 CFR 219, 10 U.S.C. 980, and DoDI 3216.02, as well as other applicable federal and state regulations. Contractors/grantees must be cognizant of and abide by the additional restrictions and limitations imposed on the DoD regarding research involving human subjects, specifically as regards vulnerable populations (32 CFR 219 modifications to subparts B-D of 45 CFR 46), recruitment of military research subjects (32 CFR 219), and surrogate consent (10 U.S.C. 980). The regulations mandate that all DoD activities, components, and agencies protect the rights and welfare of human subjects of study in DoD-supported research, development, test and evaluation, and related activities hereafter referred to as “research”. The requirement to comply with the regulations applies to new starts and to continuing research.

For Contracts, the appropriate clauses shall be added.

2) ANIMAL USE. Assistance Instruments Only. DODI 3216.01, provides policy and requirements for the use of animals in DOD-funded research. The DoD definition of animal is any live nonhuman vertebrate. All proposals that involve the use of animals must address DoDI compliance with DoDI 3216.01.

Provisions include rules on animal acquisition, transport, care, handling, and use in 9 CFR parts 1-4, Department of Agriculture rules implementing the Laboratory Animal Welfare Act of 1966 (7 U.S.C. 2131-2156), and guidelines in the National Academy of Sciences (NAS)

“Guide for the Care and Use of Laboratory Animals” (1996), including the Public Health Service Policy and Government Principles Regarding the Care and Use of Animals in Appendix D to the Guide.

For Contracts, the appropriate clauses shall be added.

3) BIOLOGICAL DEFENSE SAFETY PROGRAM REQUIREMENTS: For All Awards. Successful offerors whose Principal Investigators are conducting research with Bio-safety Levels 3 and 4 material must prepare a Facility Safety Plan in accordance with 32 Code of Federal Regulations (CFR) 626.18. See URL: www.access.gpo.gov/nara/cfr/waisidx_99/32cfr626_99.html for a copy of 32 CFR 626.18, Biological Defense Safety Program.

4) MILITARY RECRUITING: For Assistance Instruments Only. This is to notify potential offerors that each grant or cooperative agreement awarded under this announcement to an institution of higher education must include the following term and condition:

"As a condition for receipt of funds available to the Department of Defense (DOD) under this award, the recipient agrees that it is not an institution of higher education (as defined in 32 CFR part 216) that has a policy of denying, and that it is not an institution of higher education that effectively prevents, the Secretary of Defense from obtaining for military recruiting purposes: (A) entry to campuses or access to students on campuses or (B) access to directory information pertaining to students. If the recipient is determined, using the procedures in 32 CFR part 216, to be such an institution of higher education during the period of performance of this agreement, and therefore to be in breach of this clause, the Government will cease all payments of DOD funds under this agreement and all other DOD grants and cooperative agreements to the recipient, and it may suspend or terminate such grants and agreements unilaterally for material failure to comply with the terms and conditions of award."

If your institution has been identified under the procedures established by the Secretary of Defense to implement Section 558, then: (1) no funds available to DOD may be provided to your institution through any grant, including any existing grant, (2) as a matter of policy, this restriction also applies to any cooperative agreement, and (3) your institution is not eligible to receive a grant or cooperative agreement in response to this solicitation.

5) MILITARY RECRUITING: For Contracts Only. This is to notify potential offerors that each contract awarded under this announcement to an institution of higher education shall include the following clause: Defense Federal Acquisition Regulation Supplement (DFARS) clause 252.209-7005, Military Recruiting on Campus.

6) SUBCONTRACTING: For Contracts Only. This section is applicable to contracts where the dollar threshold is expected to exceed to $650,000.00. Pursuant to Section 8(d) of the Small Business Act [15 U.S.C. 637(d)], it is the policy of the Government to enable small business concerns to be considered fairly as subcontractors under all research agreements awarded to prime contractors. The required elements of the Subcontracting Plan are set forth

by FAR 52.219-9 and DFARS 252.219-7003. The offeror's plan shall depict the percentage values of the option requirements separately. The information in the SB Subcontracting Plan must properly correlate with that of the offeror's SB Participation Plan. The Government's subcontracting goals for Fiscal Year 2012 (FY12) are listed below, future year goals can be found at: http://www.acq.osd.mil/osbp/gov/sbProgramGoals.shtml.

Subcontracting Plan Goals. The offeror is requested to consider, when appropriate, the Government's subcontracting goals. The goals for FY12 are as follows:

Small Business 35%
Small Disadvantaged Business 5% [FY12 goal is 3%; aim for DFARS 219.705-4(d) compliance]
Women-Owned Small Business 3%
HUBZone Small Business: 3%
Service-Disabled Veteran-Owned Small Business 3%
Historically Black Colleges/Universities or Minority Serving Institutions 3%

3. Reporting:

Additional reports including number and types will be specified in the award document, but will include as a minimum monthly financial status reports. The reports shall be prepared and submitted in accordance with the procedures contained in the award document and mutually agreed upon before award. Reports and briefing material will also be required as appropriate to document progress in accomplishing program metrics. A final report that summarizes the project and tasks will be required at the conclusion of the performance period for the award.

ARMY MANPOWER CONTRACTOR REPORTING: For Contracts Only. The Office of the Assistant Secretary of the Army (Manpower & Reserve Affairs) operates and maintains a secure Army data collection site where the contractor will report ALL contractor manpower (including subcontractor manpower) required for performance of this contract. The contractor is required to completely fill in all the information in the format using the following web address: https://cmra.army.mil/. The required information includes: (1) Contracting Office, Contracting Officer, Contracting Officer's Technical Representative; (2) Contract number, including task and delivery order number; (3) Beginning and ending dates covered by reporting period; (4) Contractor name, address, phone number, e-mail address, identity of contractor employee entering data; (5) Estimated direct labor hours (including sub-contractors); (6) Estimated direct labor dollars paid this reporting period (including sub-contractors); (7) Total payments (including sub-contractors); (8) Predominate Federal Service Code (FSC) reflecting services provided by contractor (and separate predominant FSC for each sub-contractor if different); (9) Estimated data collection cost; (10) Organizational title associated with the Unit Identification Code (UIC) for the Army Requiring Activity (the Army Requiring Activity is responsible for providing the contractor with its UIC for the purposes of reporting this information); (11) Locations where contractor and sub-contractors perform the work (specified by zip code in the United States and nearest city, country, when in an overseas location, using standardized nomenclature provided on website); (12) Presence of deployment or contingency contract language; and (13) Number of

contractor and sub-contractor employees deployed in theater this reporting period (by country). As part of its submission, the contractor will also provide the estimated total cost (if any) incurred to comply with this reporting requirement. Reporting period will be the period of performance not to exceed 12 months ending 30 September of each government fiscal year and must be reported by 31 October of each calendar year. Contractors may use a direct XML data transfer to the database server or fill in the fields on the website. The XML direct transfer is a format for transferring files from a contractor's systems to the secure web site without the need for separate data entries for each required data element at the web site. The specific formats for the XML direct transfer may be downloaded from the web site.

G. Agency Contacts:

Questions of a technical nature are to be directed to:
The TPOCs for each area of interest are identified as part of the description of that area and may be contacted as appropriate.

Questions of a business nature are to be directed to:
usarmy.rtp.aro.mbx.baa@mail.mil

Comments or questions submitted should be concise and to the point, eliminating any unnecessary verbiage. In addition, the relevant part and paragraph of the Broad Agency Announcement (BAA) should be referenced.

H. Other Information:

Below are 2 separate outlines of the informational requirements for a sample cost proposal. H.1. is for a procurement contract and H.2 for grants, cooperative agreements and TIAs.

1. CONTRACT Proposals:

Cost Proposal – {No Page Limit}
Cover sheet to include:
(1) BAA number;
(2) Technical area;
(3) Lead Organization Submitting proposal;
(4) Type of business, selected among the following categories: "LARGE BUSINESS", "SMALL DISADVANTAGED BUSINESS", "OTHER SMALL BUSINESS", "HBCU", "MI", "OTHER EDUCATIONAL", OR "OTHER NONPROFIT";
(5) Contractor's reference number (if any);
(6) Other team members (if applicable) and type of business for each;
(7) Proposal title;
(8) Technical point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), electronic mail (if available);
(9) Administrative point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), and electronic mail (if available);

(10) Award instrument requested: cost-plus-fixed-free (CPFF), cost-contract—no fee, cost sharing contract – no fee, or other type of procurement contract (specify).
(11) Place(s) and period(s) of performance;
(12) Total proposed cost separated by basic award and option(s) (if any);
(13) Name, address, and telephone number of the proposer's cognizant Defense Contract Management Agency (DCMA) administration office (if known);
(14) Name, address, and telephone number of the proposer's cognizant Defense Contract Audit Agency (DCAA) audit office (if known);
(15) Date proposal was prepared;
(16) DUNS number;
(17) TIN number; and
(18) Cage Code;
(19) Subcontractor Information; and
(20) Proposal validity period
(21) Any Forward Pricing Rate Agreement, other such approved rate information, or such other documentation that may assist in expediting negotiations (if available).

I. Reasoning for Submitting a Strong Cost Proposal

The ultimate responsibility of the Contracting Officer is to ensure that all prices offered in a proposal are fair and reasonable before contract award [FAR 15.4]. To establish the reasonableness of the offered prices, the Contracting Officer may ask the offeror to provide various supporting documentation that assists in this determination. The offeror's ability to be responsive to the Contracting Officer's requests can expedite contract award. As specified in Section 808 of Public Law 105-261, an offeror who does not comply with a requirement to submit information for a contract or subcontract in accordance with paragraph (a)(1) of FAR 15.403-3 may be ineligible for award.

II. DCAA-Accepted Accounting System

A) Before a contract can be awarded, the Contracting Officer must confirm that the offeror has a Defense Contract Audit Agency (DCAA)-accepted accounting system in place for accumulating and billing costs under Government contracts [FAR 53.209-1(f)]. If the offeror has DCAA correspondence, which documents the acceptance of their accounting system, this should be provided to the Contracting Officer (i.e. attached or referenced in the proposal). Otherwise, the Contracting Officer will submit an inquiry directly to the appropriate DCAA office and request a review of the offeror's accounting system.

B) If an offeror does not have a DCAA-accepted accounting system in place, the DCAA review process can take several months depending upon the availability of the DCAA auditors and the offeror's internal processes. This will cause a delay in contract award.

C) For more information about cost proposals and accounting standards, view the link titled "Information for Contractors" on the main menu on their website.

III. Field Pricing Assistance

During the pre-award cost audit process, the Contracting Officer will solicit support from DCAA to determine commerciality and price reasonableness of the proposal [FAR 15.404-2]. Any proprietary information or reports obtained from DCAA field audits will be appropriately identified and protected within the Government.

IV. Sample Cost Proposal – "Piece by Piece"

A) To help guide offerors through the pre-award cost audit process, a sample cost proposal is detailed below. This sample also allows the offeror to see exactly what the Government is looking for; therefore, all cost and pricing back-up data can be provided to the Government in the first cost proposal submission. Review each cost element within the proposal, and take note of the types of documentation that the Contracting Officer will require from the offeror.

B) Direct Labor: The first cost element included in the cost proposal is Direct Labor. The Department of Defense (DoD) requires each proposed employee to be listed by name and labor category.

Below is the Direct Labor as proposed by our sample offeror:

DIRECT LABOR:		YEAR 1			YEAR 2		
Employee Name	Labor Category	Direct Hourly Rate	Hours	Total Direct Labor	Direct Hourly Rate	Hours	Total Direct Labor
Andy Smith	Program Manager	$55.00	720.00	$39,600.00	$56.65	720.00	$40,788.00
Bryan Andrew	Senior Engineer	$40.00	672.00	$26,880.00	$41.20	672.00	$27,686.40
Cindy Thomas	Principal Engineer	$50.00	512.00	$25,600.00	$51.50	512.00	$26,368.00
David Porter	Entry Level Engineer	$10.00	400.00	$4,000.00	$10.30	400.00	$4,120.00
Edward Bean	Project Administrator	$25.00	48.00	$1,200.00	$25.75	48.00	$1,236.00
Subtotal Direct Labor (DL):				$97,280.00			$100,198.40

1) For this cost element, the Contracting Officer requires the offeror to provide adequate documentation in order to determine that each labor rate for each employee/labor category is fair and reasonable. The documentation will need to explain how these labor rates were derived. For example, if the rates are DCAA-approved labor rates, provide the Contracting Officer with copies of the DCAA documents stating the approval. This is the most acceptable means of documentation to determine the rates fair and reasonable. Other types of supporting documentation may include General Service Administration (GSA) contract price lists, actual payroll journals, or Salary.com research. If an employee listed in a cost proposal is not a current employee (maybe a new employee, or one contingent upon the award of this contract), a copy of the offer letter stating the hourly rate - signed and accepted by the employee - may be provided as adequate documentation. Sometimes the hourly rates listed in a proposal are derived through subjective processes, i.e., blending of multiple employees in one labor category, or averaged over the course of the year to include scheduled payroll increases, etc. These situations should be clearly documented for the Contracting Officer.

2) Another cost element in Direct Labor is labor escalation, or the increase in labor rates from Year 1 to Year 2. In the example above, the proposed labor escalation is 3% (ex., Andy Smith increased from $55.00/hr in Year 1, by 3% to $56.65/hr in Year 2). Often times, an offeror may not propose escalation on labor rates during a 24-month period. Whatever the proposed escalation rate is, please be prepared to explain why it is fair and reasonable [ex., A sufficient explanation for our sample escalation rate would be the Government's General Schedule Increase and Locality Pay for the same time period (name FY) in the same location (name location) was published as 3.5%, therefore a 3% increase is fair and reasonable].

C) Other Direct Costs (ODCs): This section of the cost proposal includes all other directly related costs required in support of the effort i.e., materials, subcontractors, consultants, travel, etc. Any cost element that includes various items will need to be detailed in a cost breakdown to the Contracting Officer.

1) Direct Material Costs: This subsection of the cost proposal will include any special tooling, test equipment, and material costs necessary to perform the project. Items included in this section will be carefully reviewed relative to need and appropriateness for the work proposed, and must, in the opinion of the Contracting Officer, be advantageous to the Government and directly related to the specific topic.

    a) The Contracting Officer will require adequate documentation from the offeror to determine the cost reasonableness for each material cost proposed. The following methods are ways in which the Contracting Officer can determine this [FAR 15.403-1].

        i) Adequate Price Competition. A price is based on adequate price competition when the offeror solicits and receives quotes from two or more responsible vendors for the same or similar items or services. Based on these quotes, the

offeror selects the vendor who represents the best value to the Government. The offeror will be required to provide copies of all vendor quotes received to the Contracting Officer.
Note: Price competition is not required for items at or below the simplified acquisition threshold ($3,000) [FAR 15.403-1]. If an item's unit cost is less than or equal to $3,000, price competition is not necessary. However, if an item's total cost over the period of performance (unit cost * quantity is higher than $3,000, two or more quotes must be obtained by the offeror.

ii) Commercial Prices. Commercial prices are those published on current price lists, catalogs, or market prices. This includes vendors who have prices published on a GSA-schedule contract. The offeror will be required to provide copies of such price lists to the Contracting Officer.

iii) Prices set by law or regulation. If a price is mandated by the Government (i.e. pronouncements in the form of periodic rulings, reviews, or similar actions of a governmental body, or embodied in the laws) that is sufficient to set a price.

b) Below is the list of Direct Material costs included in our sample proposal:

DIRECT MATERIAL COSTS:	YEAR 1	YEAR 2
Raw Materials	$35,000.00	$12,000.00
Computer for experiments	$4,215.00	$0.00
Cable (item #12-3657, 300 ft)	$1,275.00	$0.00
Software	$1,825.00	$1,825.00
Subtotal Direct Materials Costs (DM):	$42,315.00	$13,825.00

ii) "Raw Materials": This is a generic label used to group many material items into one cost item within the proposal. The Contracts Officer will require a detailed breakout of all the items that make up this cost. For each separate item over $3,000 (total for Year 1 + Year 2), the offeror must be able to provide either competitive quotes received, or show that published pricing was used.

iii) "Computer for experiments": Again, this item is most likely a grouping of several components that make up one system. The Contracts Officer will require a detailed breakout of all the items that make up this cost. For each separate item over $3,000 (total for Year 1 + Year 2), the offeror must be able to provide either competitive quotes received, or show that published pricing was used.

iv) "Cable": Since this item is under the simplified acquisition threshold of $3,000, competitive quotes or published pricing are not required. Simply provide documentation to show the Contracting Officer where this price came from.

v) "Software": This cost item could include either one software product, or multiple products. If this includes a price for multiple items, please provide the detailed cost breakdown.
Note: The price for Year 1 ($1,825) is below the simplified acquisition threshold; however, in total (Year 1 + Year 2) the price is over $3,000, so competitive quotes or published pricing documentation must be provided.

c) Due to the specialized types of products and services necessary to perform these projects, it may not always be possible to obtain competitive quotes from more than one reliable source. Each cost element over the simplified acquisition threshold ($3,000) must be substantiated. There is always an explanation for HOW the cost of an item was derived; show us how you came up with that price!

d) When it is not possible for an offeror to obtain a vendor price through competitive quotes or published price lists, a Contracting Officer may accept other methods to determine cost reasonableness. Below are some examples of other documentation, which the Contracting Officer may accept to substantiate costs:

i) Evidence that a vendor/supplier charged another offeror a similar price for similar services. Has the vendor charged someone else for the same product? (Two (2) to three (3) invoices from that vendor to different customers may be used as evidence.)

ii) Previous contract prices. Has the offeror charged the Government a similar price under another Government contract for similar services? If the Government has already paid a certain price for services, then that price may already be considered fair and reasonable. (Provide the contract number, and billing rates for reference.)

iii) DCAA approved. Has DCAA already accepted or verified specific cost items included in your proposal? (Provide a copy of DCAA correspondence that addressed these costs.)

2) Below is the remaining ODC portion of our proposal including equipment, subcontractors, consultants, and travel. Assume in this scenario that competitive quotes or catalog prices were not available for these items:

OTHER DIRECT COSTS:	YEAR 1	YEAR 2
Equipment Rental for Analysis	$5,500.00	$5,600.00
Subcontractor - Lockheed	$25,000.00	$0.00
Consultant: John Bowers	$0.00	$12,000.00
Travel	$1,250.00	$1,250.00
Subtotal Other Direct Costs (ODC):	$31,750.00	$18,850.00

a) "Equipment Rental for Analysis": The offeror explains that the Year 1 cost of $5,500 is based upon 250 hours of equipment rental at an hourly rate of $22.00/hr. One (1) invoice from the vendor charging another vendor the same price for the same service is provided to the Contracting Officer as evidence. Since this cost is over the simplified acquisition threshold, further documentation to determine cost reasonableness is required. The offeror is able to furnish another invoice charging a second vendor the same price for the same service.

b) "Subcontractor – Lockheed": The offeror provides a copy of the subcontractor quote to the Contracting Officer in support of the $25,000 cost. This subcontractor quote must include sufficient detailed information (equivalent to the data included in the prime's proposal to the Government), so that the Contracting Officer can make a determination of cost reasonableness.

   i) As stated in Section 3.5(c)(6) of the DoD Cost Proposal guidance, "All subcontractor costs and consultant costs must be detailed at the same level as prime contractor costs in regards to labor, travel, equipment, etc. Provide detailed substantiation of subcontractor costs in your cost proposal."

   ii) In accordance with FAR 15.404-3, "the Contracting Officer is responsible for the determination of price reasonableness for the prime contract, including subcontracting costs". This means that the subcontractor's quote/proposal may be subject to the same scrutiny by the Contracting Officer as the cost proposal submitted by the prime. The Contracting Officer will need to determine whether the subcontractor has an accepted purchasing system in place and/or conduct appropriate cost or price analyses to establish the reasonableness of proposed subcontract prices. Due to the proprietary nature of cost data, the Subcontractor may choose to submit their pricing information directly to the Contracting Officer and not through the prime. This is understood and encouraged.

   iii) When a subcontractor is selected to provide support under the prime contract due to their specialized experience, the Contracting Officer may request sole source justification from the offeror.

c) "Consultant – John Bowers": Again, the offeror shall provide a copy of the consultant's quote to the Contracting Officer as evidence. In this example, the consultant will be charging an hourly rate of $125 an hour for 96 hours of support. The offeror indicates to the Contracting Officer that this particular consultant was used on a previous contract with the Government (provide contract number), and will be charging the same rate. A copy of the consultant's invoice to the offeror under the prior contract is available as supporting evidence. Since the Government has paid this price for the same services in the past, determination has already been made that the price is fair.

d) "Travel": The Contracting Officer will require a detailed cost breakdown for travel expenses to determine whether the total cost is reasonable based on Government per diem and mileage rates. This breakdown shall include the number of trips, the destinations, and the number of travelers. It will also need to include the estimated airfare per round trip, estimated car rental, lodging rate per trip, tax on lodging, and per diem rate per trip. The lodging and per diem rates must coincide with the Joint Travel Regulations. Please see the following website to determine the appropriate lodging and per diem rates: http://perdiem.hqda.pentagon.mil/perdiem/conus2009.txt. Additionally, the offeror must provide why the airfare is fair and reasonable as well. Sufficient back up for both airfare and car rental would include print outs of online research at the various travel search engines (Expedia, Travelocity, etc.) documenting the prices for airfare and car rentals thus proving why your chosen rate is fair and reasonable.

i) Below is a sample of the travel portion:

TRAVEL		Trips	Travelers	Nights	Days	Unit Cost	Total Travel
Airfare	per roundtrip	1	1			$996.00	$996.00
Lodging	per day	1	1	1		$75.00	$75.00
Tax on Lodging (12%)	per day	1	1	1		$9.00	$9.00
Per Diem	per day	1	1		2	$44.00	$88.00
Automobile Rental	per day	1	1		2	$41.00	$82.00
Subtotal Travel							$1,250.00

D) Indirect Rates: Indirect rates include elements such as Fringe Benefits, General & Administrative (G&A), Overhead, and Material Handling costs. The offeror shall indicate in the cost proposal both the indirect rates (as a percentage) as well as how those rates are allocated to the costs in the proposal.

Below is the Indirect portion of our sample proposal:

INDIRECTS	YEAR 1	YEAR 2
Subtotal Direct Labor (DL):	$97,280.00	$100,198.40
Fringe Benefits, if not included in Overhead, rate (15.0000 %) X DL =	$14,592.00	$15,029.76
Labor Overhead (rate 45.0000 %) X (DL + Fringe) =	$50,342.40	$51,852.67
Total Direct Labor (TDL):	$162,214.40	$167,080.83

1) In this example, the offeror includes a Fringe Benefit rate of 15.00% that it allocated to the Direct Labor costs. They also propose a Labor Overhead rate of 45.00% that is allocated to the Direct Labor costs plus the Fringe Benefits.

2) All indirect rates and the allocation methods of those rates must be verified by the Contracting Officer. In most cases, DCAA documentation supporting the indirect rates and allocation methods can be obtained through a DCAA field audit or proposal review. Many offerors have already completed such reviews and have this documentation readily available. If an offeror is unable to participate in a DCAA review to substantiate indirect rates, the Contracting Officer may request other accounting data from the offeror to make a determination.

E.) Cost of Money (COM): If Cost of Money (an imputed cost that is not a form of interest on borrowings (see FAR 31.205-20); an "incurred cost" for cost-reimbursement purposes under applicable cost-reimbursement contracts and for progress payment purposes under fixed-price contracts; and refers to— (1) Facilities capital cost of money (48 CFR 9904.414); and (2) Cost of money as an element of the cost of capital assets under construction (48 CFR 9904.417)) is proposed in accordance with FAR 31.205-10, a DD Form 1861 is required to be completed and submitted with the contractor's proposal.

F.) Fee/Profit: The proposed fee percentage will be analyzed in accordance with DFARS 215.404, the Weighted Guidelines Method.

G.) Subcontracting Plan: If the total amount of the proposal exceeds $650,000 and the offeror is a large business or an institute of higher education (other than HBCU/MI) and the resultant award is a contract, the offeror shall be prepared to submit a subcontracting plan for small business and small disadvantaged business concerns. A mutually agreeable plan will be included in and made a part of the contract (see the goals listed at Section II, F, 2, b).

2. GRANT and COOPERATIVE AGREEMENT Proposals:

Before award it must be established that an approved accounting system and financial management system exist.

A.) Direct Labor: Show the current and projected salary amounts in terms of man-hours, man-months, or annual salary to be charged by the principal investigator(s), faculty, research associates, postdoctoral associates, graduate and undergraduate students, secretarial, clerical, and other technical personnel either by personnel or position. State the number of man-hours used to calculate a man-month or man-year. For proposals from universities, research during the academic term is deemed part of regular academic duties, not an extra function for which additional compensation or compensation at a higher rate is warranted. Consequently, academic term salaries shall not be augmented either in rate or in total amount for research performed during the

academic term. Rates of compensation for research conducted during non-academic (summer) terms shall not exceed the rate for the academic terms. When part or all of a person's services are to be charged as project costs, it is expected that the person will be relieved of an equal part or all of his or her regular teaching or other obligations. For each person or position, provide the following information:

(1) The basis for the direct labor hours or percentage of effort (e.g., historical hours or estimates).

(2) The basis for the direct labor rates or salaries. Labor costs should be predicted upon current labor rates or salaries. These rates may be adjusted upward for forecast salary or wage cost-of-living increases that will occur during the agreement period. The cost proposal should separately identify the rationale applied to base salary/wage for cost-of-living adjustments and merit increases. Each must be fully explained.

(3) The portion of time to be devoted to the proposed research, divided between academic and non-academic (summer) terms, when applicable.

(4) The total annual salary charged to the research project.

(5) Any details that may affect the salary during the project, such as plans for leave and/or remuneration while on leave.

B.) Fringe Benefits and Indirect Costs (Overhead, General and Administrative, and Other): The most recent rates, dates of negotiation, the base(s) and periods to which the rates apply must be disclosed and a statement included identifying whether the proposed rates are provisional or fixed. If the rates have been negotiated by a Government agency, state when and by which agency. A copy of the negotiation memorandum should be provided. If negotiated forecast rates do not exist, offerors must provide sufficient detail to enable a determination to be made that the costs included in the forecast rate are allocable according to applicable OMB Circulars or FAR/DFARS provisions. Offerors' disclosure should be sufficient to permit a full understanding of the content of the rate(s) and how it was established. As a minimum, the submission should identify:

(1) All individual cost elements included in the forecast rate(s);

(2) Bases used to prorate indirect expenses to cost pools, if any;

(3) How the rate(s) was calculated;

(4) Distribution basis of the developed rate(s);

(5) Bases on which the overhead rate is calculated, such as "salaries and wages" or "total costs," and

(6) The period of the offeror's fiscal year.

C.) Permanent Equipment: If facilities or equipment are required, a justification why this property should be furnished by the Government must be submitted. State the organization's inability or unwillingness to furnish the facilities or equipment. Offerors must provide an itemized list of permanent equipment showing the cost for each item. Permanent equipment is any article or tangible nonexpendable property having a useful life of more than one year and an acquisition cost of $5,000 or more per unit. The basis for the cost of each item of permanent equipment included in the budget must be disclosed, such as:

(1) Vendor Quote: Show name of vendor, number of quotes received and justification, if intended award is to other than lowest bidder.

(2) Historical Cost: Identify vendor, date of purchase, and whether or not cost represents lowest bid. Include reason(s) for not soliciting current quotes.

(3) Engineering Estimate: Include rationale for quote and reason for not soliciting current quotes. If applicable, the following additional information shall be disclosed in the offeror's cost proposal:

(4) Special test equipment to be fabricated by the awardee for specific research purposes and its cost.

(5) Standard equipment to be acquired and modified to meet specific requirements, including acquisition and modification costs, listed separately.

(6) Existing equipment to be modified to meet specific research requirements, including modification costs. Do not include equipment the organization will purchase with its funds if the equipment will be capitalized for Federal income tax purposes. Proposed permanent equipment purchases during the final year of an award shall be limited and fully justified.

(7) Grants and cooperative agreements may convey title to an institution for equipment purchased with project funds. At the discretion of the contracting/grants officer, the agreement may provide for retention of the title by the Government or may impose conditions governing the equipment conveyed to the organization. The Government will not convey title to commercial contractors.

D.) Travel: Forecasts of travel expenditures (domestic and foreign) that identify the destination and the various cost elements (airfare, mileage, per diem rates, etc.) must be submitted. The costs should be in sufficient detail to determine the reasonableness of such costs. Allowance for air travel normally will not exceed the cost of round-trip, economy air accommodations. Specify the type of travel and its relationship to the research project. Requests for domestic travel must not exceed $3,000 per year per

principal investigator. Separate, prior approval by the ARL is required for all foreign travel (i.e., travel outside the continental U.S., its possessions and Canada). Foreign travel requests must not exceed $1,800 each per year per principal investigator. Special justification will be required for travel requests in excess of the amounts stated above and for travel by individuals other than the principal investigator(s). Individuals other than the principal investigator(s) are considered postdoctoral associates, research associates, graduate and undergraduate students, secretarial, clerical, and other technical personnel. Additional travel may be requested for travel to Army laboratories and facilities to enhance agreement objectives and to achieve technology transfer.

E.) Participant Support Costs: This budget category refers to costs of transportation, per diem, stipends, and other related costs for participants or trainees (but not employees) in connection with ARL-sponsored conferences, meetings, symposia, training activities, and workshops (see the "Other Programs" section as described earlier in this BAA). Generally, indirect costs are not allowed on participant support costs. The number of participants to be supported should be entered in the parentheses on the budget form. These costs should also be justified in the budget justification page(s) attached to the cost proposal.

F.) Materials, Supplies, and Consumables: A general description and total estimated cost of expendable equipment and supplies are required. The basis for developing the cost estimate (vendor quotes, invoice prices, engineering estimate, purchase order history, etc.) must be included. If possible, provide a material list.

G.) Publication, Documentation, and Dissemination: The budget may request funds for the costs of preparing, publishing, or otherwise making available to others the findings and products of the work conducted under an agreement, including costs of reports, reprints, page charges, or other journal costs (except costs for prior or early publication); necessary illustrations, cleanup, documentation, storage, and indexing of data and databases; and development, documentation, and debugging of software.

H.) Consultant Costs: Offerors normally are expected to utilize the services of their own staff to the maximum extent possible in managing and performing the project's effort. If the need for consultant services is anticipated, the nature of proposed consultant services should be justified and included in the technical proposal narrative. The cost proposal should include the names of consultant(s), primary organizational affiliation, each individual's expertise, daily compensation rate, number of days of expected service, and estimated travel and per diem costs.

I.) Computer Services: The cost of computer services, including computer-based retrieval of scientific, technical, and educational information, may be requested. A justification/explanation based on the established computer service rates at the proposing organization should be included. The budget also may request costs, which must be shown to be reasonable, for leasing automatic data processing equipment. The purchase of computers or associated hardware and software should be requested as items of equipment.

J.) Subawards (subcontracts or subgrants): A precise description of services or materials that are to be awarded by a subaward must be provided. For subawards totaling $10,000 or more, provide the following specific information:

(1) A clear description of the work to be performed.

(2) If known, the identification of the proposed subawardee and an explanation of why and how the subawardee was selected or will be selected.

(3) The identification of the type of award to be used (cost reimbursement, fixed price, etc.).

(4) Whether or not the award will be competitive and, if noncompetitive, rationale to justify the absence of competition.

(5) A detailed cost summary.

K.) Other Direct Costs: Itemize and provide the basis for proposed costs for other anticipated direct costs such as communications, transportation, insurance, and rental of equipment other than computer related items. Unusual or expensive items shall be fully explained and justified.

L.) Fixed Fee: Fixed fee is not allowed for assistance instruments.

M.) Subcontracting Plan: Subcontracting plans do not apply to assistance instruments.

CONTRACT FACILITIES CAPITAL COST OF MONEY: If cost of money is proposed, a completed Contract Facilities Capital Cost of Money (FCCM) (DD Form 1861) is required.