FY24 LDRD Calls & Research Needs

Thank you for your interest in the Sandia National Laboratories LDRD program! Each program area below contains a description of the program, along with high-level research needs. Please use the form linked in the email to submit your research summaries that align with the program areas below. Each research need contains a unique identifier that you will use a key to select on the form. You may select more than one area per submission. Contact academicprograms@sandia.gov *with any questions.*

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University Partnerships IA Collaborative Opportunities

Advanced Science & Technology (AS&T)

The Advanced Science and Technology (AS&T) LDRD Mission Foundation Investment Area (IA) invests in building Labs' expertise in discovery research for science and engineering applications relevant to national security missions. The IA rests on the DOE Office of Science (SC), which rests on maturing foundational concepts underlying disruptive science and technologies and creating and advancing differentiating capabilities. This includes developing and training new scientific leaders and building cross-cutting initiatives.

AS&T seeks collaborators for our Office of Science-focused fundamental discovery research that underpins cross-cutting technologies in next generation microelectronics, reducing uncertainty in earth and environmental systems, and reducing CO_2 emissions through carbon negative processes. Proposals will complement Sandia Office of Science program areas in advanced scientific computing research, chemical sciences, geosciences, materials sciences, earth & environmental system science, fusion energy sciences, and/or biological systems science.

Biosciences (Bio)

The Bioscience Research Foundation will direct its LDRD investment to sponsor high-impact biological research and game-changing biotechnology development that creates and grows capabilities aligned with Sandia's biology mission. We will prioritize our investments to support the NNSA Bioassurance Program goal to anticipate and mitigate risks due to rapidly advancing biotechnology and biothreats. We solicit proposals that will establish a strategic advantage for Sandia by pairing the capabilities and applications described below. We also encourage discovery science proposals that explore disruptive innovations in these areas. Proposals that produce incremental scientific advances are discouraged.

Research Needs

Predictive Biology Capability

- Predictive biology is the development of robust, experimentally validated models that describe, in advance, the outcome or impact of changes made to a biological system either through genetic engineering or environmental control.
- We are interested in the generation of predictive biological models to assure robust biomanufacturing and biodefense.
- We will prioritize proposals that:
    - Develop automated, high-throughput experimental platforms for data collection to inform a predictive model relevant to biomanufacturing or high-priority pathogens. We are particularly interested in platforms that characterize phenotypic expression to complement genetic profiling, lead to accelerated detection and countermeasure development, or both.

Synthetic Biology Capability

- For this call, synthetic biology is the design and construction of new biological parts, devices, and systems, and the re-design of existing, natural biological systems to produce living systems with enhanced functionalities such as the bioproduction of molecules and materials.

- We are seeking proposals that build synthetic biology tools and capabilities to enable biopreparedness and a safe and secure bioeconomy.
- We will prioritize proposals that:
  - Invent new, inherently secure approaches to accelerate the design-build-test-learn cycle for improving chemical production in novel microorganisms, either experimentally or via ML/AI. We have particular interest in sustainable aviation fuel as a target product.
  - Develop new genetic approaches and tools to safely enable strain engineering and optimization or to understand gene function in recalcitrant, commercially important microorganisms.
  - Identify and characterize the interactions between microorganisms and their macro-environment to mitigate scale-up risks when transitioning from laboratory studies to pilot demonstrations in new biomanufacturing systems.
  - Invent new, inherently secure approaches to modify and control microbiome communities.

Biodetection Capability

- In the context of this call, biodetection is the search for molecular signatures, molecular assays, and sensor technologies that identify the presence of, or exposure to, a biological agent within any sample matrix and the deployment of biodetection systems to the point-of-need.
- We will fund novel biodetection R&D that addresses the challenges of agent-agnostic detection with high specificity, low false alarm rate, low cost, and ease-of-use.
- We will prioritize biodetection proposals that:
  - Control and inform the scale-up of biomanufacturing processes from test tube to industrial scale.
  - Demonstrate methods to detect changes in protein or nucleic acid sequences consistent with biodetection goals for high specificity, low false alarm rate, low cost, and ease-of-use.
  - Discover novel transduction mechanisms leading to automated terrestrial carbon sequestration measurements to reduce uncertainty in earth system models.
  - Demonstrate methods that could be deployed for global biomonitoring systems.

Computing and Information Sciences (CIS)

The Computing and Information Sciences Research Foundation (CIS RF) advances research and development in computing, mathematics, and information sciences to position Sandia at the frontiers and intersection of science, engineering, and national security.

CIS Research Focus Areas include:

- Trusted Artificial Intelligence
- Computational Decision Science
- Information Science and Technology
- Quantum Information Sciences
- Human-Machine Teaming to Enable Decision Making

Earth Sciences (Earth)

All national security challenges have some intersection with earth science. Sandia's missions focus on the scientific and engineering aspects of national security. The Earth Science Research Foundation (RF) emphasizes "Quantitative Earth Science for National Security." The intersection of national security and

Earth Science occurs across a wide zone spanning tens of kilometers above to several kilometers below the earth's surface. Across this wide zone encompassing the solid earth, oceans, and the atmosphere, Sandia's Earth Science R&D must address the coupled thermal, chemical, biological, hydrological, physical, energy propagation, and mechanical behavior of naturally occurring, significantly heterogeneous, and dynamic materials, ensuring integrated understanding and information across scales ranging from nanometers to hundreds of kilometers. Quantitative elements include detailed characterization, data analytics, and machine learning applied to both interpretation and simulation, new numerical techniques, and all forms of modeling. For FY23, the Earth Science RF will continue its focus on research problems at the intersection of climate change and national security. Talent pipeline development is also a priority, so university partnerships with student and postdoc engagement in projects are strongly encouraged.

Research Needs

- Developing sensors and systems to interrogate Earth systems
- Analyzing and experimenting to characterize, quantify, and manipulate Earth properties
- Coupling Earth science and engineering tools
- Developing simulation tools for predicting Earth system behavior over orders of magnitude in space and time for solid earth, oceans, hydrosphere, or atmospheric materials at in situ conditions
- Developing insights from examination of processes at the interfaces among various Earth

Focus areas for the FY24 call include earth science research that advances:

- Geologic storage of hydrogen
- Carbon capture, utilization, and storage
- Geothermal energy optimization
- Greenhouse gas monitoring
- Climate impact analysis, including extreme weather analysis
- Understanding of climate intervention approaches and risks
- Understanding of fundamental earth system processes—through sensing, analysis, and modeling—that limit the fidelity of climate models such as E3SM, such as the release of methane from thawing permafrost

Energy & Homeland Security (E/HS)

Sandia's Energy & Homeland Security (E/HS) portfolio secures the nation's critical infrastructures and environment against attacks, threats, and climate change by performing world-class research and development (R&D). The R&D needs presented in the call are focused on achieving goals in our Energy strategy and strengthening Homeland Security differentiating capabilities. The Energy goals are to create & assure a resilient and efficient energy infrastructure, to secure a trusted energy supply chain, and to reduce carbon & greenhouse gas emissions. The Homeland Security Programs leverage core capabilities in four strategic priority areas: supporting data-informed decision-making; in cyber, leveraging our deep knowledge of threats to protect .gov networks and data; focusing on emerging threats and enabling

what-if scenario analyses for physical security systems; and countering pandemics & weapons of mass destruction.

High-priority research needs fall into three categories:

1. Data Science and Decision Analytics,
2. Sensing and Automation, and
3. Materials and Technologies.

Engineering Sciences (ES)

The Engineering Sciences Research Foundation (ESRF) drives understanding and innovation by integrating theory, computational simulation, and experimental discovery and validation to understand, predict and control the behavior of complex physical phenomena and engineered systems. In particular, the ESRF provides leadership and stewardship for a set of critical technical capabilities: aerosciences, combustion/fire sciences, fluid mechanics, energetics, shock physics, solid mechanics, structural dynamics, thermal sciences and computational simulation technologies.

The ESRF seeks foundational, high risk/payoff, leading-edge R&D that can have application to any of Sandia's missions. ESRF seeks proposals that are more foundational in nature (i.e., lower TRL) and mission-inspired, which could have eventual impact to one or more mission areas. Special consideration will be given to "Discover" proposals which seek to advance our scientific understanding by focusing on fundamental/innovative discovery research in one or more Engineering Science disciplines.

Envision a future where a designer, production engineer, and qualification/test lead can hypothesize a design, virtually construct, and evaluate reliable digital representations of all the important combined environments (including manufacturing environments effecting as-built state) in real-time to make credible high consequence decisions with known and quantified risks. Common models with hardware integration allowing physical prototype realization and digital assimilation of inspection and validation data as well as processing and surveillance data from the component to the full system level throughout the product lifecycle could significantly accelerate all phases of development from concept to qualification. This digital engineering vision would enable costs (including energy consumption) and product development and realization times to be reduced. To enable this vision, Engineering Science capabilities will need to be responsive in all aspects of testing, diagnostics, simulation, and data analysis.

The Engineering Sciences Investment Area Team (IAT) is soliciting proposals in the four identified thrust areas below necessary to help realize this described vision:

- *Fundamental and Coupled Physics Phenomena* – discovery of fundamental, coupled physical phenomena in terms of characteristic length and time scales and development of credible engineering science models needed to predict the as-built manufactured/assembled state performance of engineered systems.

- *Next Generation Engineering Simulation* – discovery of algorithms and methods as well as development of efficient and accurate modeling and simulation techniques are required in the design, development, qualification, and sustainment stages of complex systems, across a wide variety of length and time scales.

- *Diagnostics and Experimental Capabilities for Engineering Applications* – discovery research and development of novel diagnostics and experimental testing capabilities are needed to capture phenomena and responses across multiple time and length scales up to and including the system level.

- *Engineering Data Integration and Interrogation* – formulation and integration of data science techniques to identify/discover and extract the physics knowledge and trends hidden in massive engineering data ensembles (either experiments, computational simulation, or a combination of the two) or large single data sets exhibiting extreme temporal and spatial resolution.

Global Security (GS)

The Global Security (GS) LDRD Investment Area (IA) seeks a broad spectrum of R&D efforts that advance Sandia's ability and vision to deliver innovative engineering solutions that protect the nation from strategic threats at home and abroad. The GS Mission Foundation (MF) aims to further advance Sandia's technical capabilities through R&D investments and support GS' three enduring missions: Global Monitoring, Preventing Proliferation, and Nuclear Weapon Security.

Research Needs:

Weapons of Mass Destruction Security (WMDS):

- **Physical Security System Technologies**: Revolutionary solutions for the physical security of sites and assets from cradle to grave including:
    - Novel methods to improve efficiency, efficacy, and lower lifecycle costs
    - Innovative approaches for highly reliable and secure wireless communications and power
    - Robust command and control, human factor impacts, intelligent threat awareness, innovative graded security priorities and novel approaches to controlling and interacting with environments within secure areas
    - Mobile/adaptive autonomous sensing, sensor fusion, and advanced assessment techniques and algorithms
    - Research improving sensor implementation for nuisance alarms, detection, classification, and testing
    - Novel materials, advanced manufacturing methods and active deterrent systems to improve development and implementation of delay and sensing
    - Algorithms for innovative response force tactics, improved technological force multipliers, and cooperative human/technology strategies for real time engagements.
- **Uncrewed systems (UxS) and counter-UxS (CUxS):** Novel methods for implementing and countering UxS and approaches that address the continuous evolution of UxS technologies and threats. Ideas for developing or mitigating autonomous UxS technologies; transformative

concepts for both deploying and detecting/mitigating UxS swarms/collectives; differentiating ideas for the deployment of low signature, high resilience UxS technologies; novel sensing approaches, and innovative algorithm ideas will also be considered.

- **Ensuring asset safety and security**: Transformative concepts and approaches to address the security of assets, innovative materials, and other technologies, especially in contested environments and considering emerging technologies; and novel ideas and methods that address asset safety and transportation challenges.
- **Enhancing WMD response**: Game-changing technologies for rapid identification, assessment, defeat, and attribution of CBRN WMDs; novel techniques and tools to mitigate and manage consequences of a WMD; decision-making tools; and novel concepts and technologies to advance WMD response capabilities (minimizing response timelines, deploying threat-relevant defeat technologies, and improving assessments [including human factors]) and technologies to reduce Nuclear Forensics attribution timelines.
- **New reactor technologies**: Approaches for assessing proliferation challenges from emerging reactor technologies; analysis and quantification of safeguards and security risks including non-traditional fuel cycles and advanced reactors and small modular reactors (AR/SMR); quantifying plutonium inventories and associated uncertainties during the life cycle of AR/SMR; new technologies to improve delay/response of physical protection systems for SMRs; and scientifically defendable methodologies to mitigate the insider threat.
- **Weaponization detection**: Novel methods to detect and characterize nuclear weapon development processes and testing by addressing novel signatures or threats from disruptive/emerging technologies (e.g., advanced technologies/methods). Consideration will be given to advancing the state-of-the-art for mod/sim capabilities.
- **WMD risk reduction and treaty monitoring/verification**: New technologies to support future monitoring and verification needs for arms control and safeguards agreements. Scientific basis for Integrated Deterrence across domains to provide the technical basis for risk reduction strategies. Technologies for monitoring strategic delivery vehicles (nuclear and non-nuclear). Technologies to assist on-site inspectors, including research to understand and mitigate the effects of disinformation and other human factors on inspectors' abilities to assess complex engineering systems.
- **Chemical and biological safeguards**: Innovative approaches to chemical and biological safeguards and security in limited resource environments. Also of interest are pre- and post-epidemic indicators, characterization of novel non-biological indicators of outbreaks, and post-epidemic forensics. Approaches to informing and developing safeguards for the bioeconomy. Scientific basis for assessing and mitigating proliferation risks posed by synthetic biology.
- **AI augmentation and modeling/simulation:** Innovative applications of AI technologies for GS missions in threat assessment, nonproliferation, and security.

Space and Remote Sensing (SRS):

- Remote sensing algorithms for near-real-time multi-INT (multi-intelligence) fusion leveraging remote sensing satellite data and other disparate data sources (e.g., seismic, infrasound, other ground sensors, or non-traditional sources). Multi-INT fusion seeks to combine information from a wide variety of data sources to achieve analysis and decision, supporting inferences not

achievable with a single source such as maintenance of custody and characterization for objects or events of interest.

- Advanced data analytics techniques with the potential to facilitate earlier proliferation detection, improve target discrimination and characterization, and improve decision making.
- Research to improve detection, location, and yield estimation for surface interacting explosions.
- Research to combine multiple data types (seismic, infrasound, EM, etc.) within statistical frameworks to improve detection, location, and characterization of underground nuclear explosions.
- New techniques or algorithms to detect low signal-to-noise ratio (SNR) targets in the presence of high intensity backgrounds. Algorithms that could be mapped to field-programmable gate arrays to enable increased on-board, real-time processing, are of particular interest.
- Advanced sensor designs for space-based applications ranging from the ultraviolet to long-wave infrared, including components that could transform performance of space-based sensing applications. Technologies of interest include noise rejection via common-mode or other techniques to improve signal-to-noise and source detection/identification. Technologies supporting the rapid development and realization of opto-mechanical systems for small-satellites and related applications.
- Research in testing and mitigation of natural and strategic radiation effects on electronic components for remote sensing systems. Development and testing on high-performance computing components like neuromorphic, III-V, heterointegrated, and silicon photonics are all of interest.

Materials Science (MS)

The Materials Science Research Foundation (MSRF) Investment Area (IA) advances, sustains, supports, and nurtures the materials science capabilities that Sandia needs to: (1) enable science-based materials solutions for enduring and emerging missions and national needs; (2) support the materials discovery, synthesis, characterization, and processing competencies underpinning current and future materials applications; (3) help maintain Sandia's leadership in the international scientific community; and (4) enable new missions, research directions, and/or scientific opportunities for Sandia. The MSRF emphasizes innovative and hypothesis-driven science efforts that combine theory, computation, and experiments, as appropriate, to gain new insights, advance the frontier-of-knowledge, and foster new initiatives and collaborations, positioning Sandia to remain a leader in emerging areas of materials science and technology (S&T).

MSRF aims to advance the state-of-knowledge in the field of materials science and enable current and future mission success by stewarding the following core research areas: Structural Materials, Organic Materials, Electronic and Optical Materials, Materials Surfaces and Interfaces, and Plasma, Ionics and Energetic Materials. Additionally, the development of advanced measurement science capabilities and innovative theoretical and computational approaches and concepts will be considered as they contribute to a healthy foundational materials capability.

Nanodevices and Microsystems (NM)

The Nanodevices and Microsystems Research Foundation (NMRF) supports Sandia's strategic objectives by promoting creative, leading-edge, and high-impact fundamental R&D efforts that are foundational to all of Sandia's enduring and emerging missions. These R&D efforts strive to discover and control new phenomena at the nanoscale and microscale; and create or prove new concepts, devices, components, and microsystems.

Research Needs:

Trusted Resilient Microsystems: The development of concepts, devices and tools that enable the understanding and creation of extreme-environment-hardened microelectronics and microsystems that are resistant to subversion. This includes proposals that seek to understand the impact of combined extreme environments on microsystem performance (ionizing radiation with high temperature, high power electromagnetic radiation, high shock, etc.). Design and integration approaches to enhance intrinsic manufacturability and predictive reliability are of interest.

Advanced Computing Technologies: The development of nanoscale and microscale concepts, devices, tools, and systems that extend performance improvements beyond Moore's Law, including quantum computing concepts.

Optoelectronics of the Future: The discovery and creation of advanced optoelectronics, at the nanoscale and microscale, which provide new functionality.

Advanced Microsystem Sensor Technologies: The development of nanoscale and microscale concepts, devices and systems that enable physical, chemical, radiation, nuclear materials, and explosives detection that exceed current limitations in selectivity, sensitivity, and/or robustness.

Nanoscale- and Microscale-enabled Performance: The discovery and exploitation of new functionality that results from phenomena that are unique to the nanoscale and microscale. This thrust seeks to invest in enabling phenomena that result from scale-dependent effects such as non-continuum and quantum phenomena.

National Security Programs (NSP)

The National Security Programs (NSP) Mission Foundation (MF) funds innovative R&D to enable trusted, threat-informed, pathfinder technologies and systems for the Department of Defense (DOD), Intelligence Community (IC), and other government agency missions. The NSP MF IA focus areas are aligned with the NSP Strategic Plan and portfolio technology focus areas. The sub-Investment Areas (sub-IAs) are: Cyber Innovation (CYBER); Heterogeneous Integration & Trusted Strategic Radiation-Hardened Microsystems (HI&TSRH); Innovation for Proliferation Assessments (IPA); and Radio Frequency Supremacy & Hypersonics (RFS&H).

Cyber Innovation (CYBER)

The CYBER focus area applies science and engineering principles to understand and enhance the secure operation of complex, high-consequence national security systems in adversarial environments. We seek innovative proposals to address all aspects of the systems stack including hardware, software, complex systems, and data with an emphasis in the following areas:

Research Needs

- **Hardware Systems Understanding**: The ability to characterize how security vulnerabilities and mitigations manifest in the physical device, environment, emanations, programming and dynamic operation of microelectronic devices including processors, field-programmable gate arrays (FPGAs), memories, microcontrollers and others.
- **Software Systems Understanding**: Assurance and vulnerability research of software system purpose, capability, flaws, communication and data processing and storage. Techniques that advance static or dynamic analyses are encouraged.
- **Mobile & Internet of Things (IoT)**: Understanding of mobile and IoT security and trust paradigms disrupted by the introduction of 5G networks. Innovative techniques that address the complexity of modern and future wireless protocols, networks (radio access and core), software and hardware.
- **Mission Analytics**: Statistical analysis, data science and machine learning innovations that advance our ability to answer national security mission questions.
- **Cyber Physical Systems**: Advances in co-design and analysis of security architectures, data-driven modeling, and understanding of embedded systems and communication protocols that protect and control physical process networks.

<u>Heterogeneous Integration & Trusted Radiation-Hardened Microsystems (HI&TRH)</u>

The HI&TRH focus area seeks solutions to integrate diverse technology components into a higher-level microsystem assembly with improved performance and optimal space, weight, and power for trusted and/or radiation-hardened applications.

Research Needs

- Integration of separately manufactured components into a higher-level microsystem assembly that provide enhanced functionality and improved operating characteristics
- Techniques for incorporating multiple disparate technologies such as complementary metal–oxide–semiconductor (CMOS) logic and memory, compound semiconductor microelectronics and photonics, silicon photonics, micro-electro-mechanical systems devices, passive components, and sub-systems
- Computing capabilities that can provide insight into effects of heterogeneous integration on TRH performance for a broad range of solution options
- New/modified integration processes that enable low-cost, low-volume, rapid R&D and prototyping efforts with a variety of technologies
- New and improved failure analysis capabilities and methods for advanced 3D integrated microsystems.
- Understanding of extreme environment effects in 3D integrated microsystems
- Development of predictive capabilities for 3D integrated microsystems in harsh environments (temperature range, shock/vibration, and radiation).

<u>Innovation for Proliferation Assessments (IPA)</u>

IPA is focused on identifying multidisciplinary approaches for revolutionizing the detection, assessment, and mitigation of current and future threats.

Research needs

- Autonomous sensing systems and analysis to include data analytics
- Emerging technology areas including additive manufacturing, semiconductors, next gen computing, and critical infrastructure
- Simulation and data analytical tools that extract signposts, indicators, and trends

Radio Frequency Supremacy & Hypersonics (RFS&H)

The RFS&H focus area needs to understand the various effects of system design, components, and materials on hypersonic and sensor systems.

Research Needs

- Global Positioning System (GPS)-denied navigation and control
- Advanced waveform research that enables resilient, agile processing for radio frequency (RF) image formation, communications, autonomy, and sensor systems
- Multi-mission RF architectures using trusted electronic systems with smaller size, weight, and power
- Novel tools and techniques enabling rapid, physics-based concept exploration and design optimization

Model-based systems engineering (MBSE) approaches for linking high fidelity electromagnetic (EM) models to effects previously only revealed via measurement

New Ideas (NI)

- Fundamental research in fields of current interest to Sandia that are outside the strategy space of the other Investment Areas (IAs)
- Research at the boundaries between IAs, interdisciplinary topics, and unconventional ideas
- Ideas that propose nascent research in an emerging new research field that may become relevant for national security
- Out-of-the-box approaches to address national security needs

Radiation, Electrical, & High Energy Density Science (REHEDS)

The Radiation, Electrical, and High Energy Density Sciences (REHEDS) LDRD Investment Area (IA) seeks to advance the fundamental understanding of the science of nuclear weapons and their effects. This understanding is critical for the present stockpile as well as for systems of the future as articulated in the Nuclear Posture Review and the Sandia Nuclear Deterrence (ND) Strategy. The REHEDS IA looks at four key discipline areas to advance this understanding, each of which play a pivotal role in supporting a safe, secure, and reliable stockpile that is viable today and will also be robust to evolving threats and technological surprise. These four disciplines include:

- ***Radiation Effects Science*** *— This discipline focuses on understanding the effects caused by single and combined radiation environments.*
- ***High Energy Density Science*** *— This discipline focuses on the experimental, theoretical, and computational study of material properties, radiation transport, inertial confinement fusion, and other physical processes at extreme temperatures, densities, and pressures.*
- ***Electrical & Electromagnetic Science*** *— This discipline focuses on understanding the effects of electromagnetic radiation, with a particular focus on electrical and electro-optical circuits.*
- ***Pulsed Power Science and Technologies*** *— This discipline focuses on understanding the physical principles that underlie the efficient creation and application of electrical energy through pulsed power technologies.*

Research Needs:

- Experimental, computational, and/or analytical studies to promote greater understanding of the effects produced by neutron, gamma, x-ray, or electromagnetic radiation – or any combination of these – on components and circuits
- Diagnostics for combined radiation environments, particularly ones that can discriminate between the constituent radiations in the environment (e.g., gamma relative to neutron, etc.)
- Modeling and analyses of inertial fusion platforms and the properties of materials used in these platforms
- Modeling and measurement of radiation emissions from inertial fusion platforms
- Magnetized plasma physics, fusion, and astrophysics
- Material physics including application to pulsed power technology, HED targets, and geophysics/planetary science
- Prediction and measurement of field coupling in high-Q cavities in adverse environments
- Exploration of the utility and approaches to artificial intelligence and related data analytics for the analysis of fused test and simulation data for high energy density and radiation experiments
- High voltage breakdown, power flow, and plasma formation in pulsed power systems
- Avenues for predictive maintenance to improve reliability of pulsed power systems