Multimodal Sensor Systems for Precision Health Enabled by Data Harnessing, Artificial Intelligence, and Learning (SenSE)

PROGRAM SOLICITATION
NSF 20-556

National Science Foundation

Directorate for Engineering
Division of Electrical, Communications and Cyber Systems
Division of Chemical, Bioengineering, Environmental and Transport Systems
Division of Civil, Mechanical and Manufacturing Innovation

Directorate for Mathematical and Physical Sciences
Division of Mathematical Sciences

Directorate for Computer and Information Science and Engineering
Division of Information and Intelligent Systems

Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

June 08, 2020

IMPORTANT INFORMATION AND REVISION NOTES

Please Note:

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards: separately submitted collaborative proposals are not permitted and will be returned without review.

Proposal titles should begin with the prefix "SenSE:"

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) (NSF 20-1), which is effective for proposals submitted, or due, on or after June 1, 2020.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

Multimodal Sensor Systems for Precision Health Enabled by Data Harnessing, Artificial Intelligence, and Learning (SenSE)

Synopsis of Program:

The National Science Foundation (NSF) through its Divisions of Electrical, Communications and Cyber Systems (ECCS); Chemical, Bioengineering, Environmental and Transport Systems (CBET); Civil, Mechanical and Manufacturing Innovation (CMMI); Information and Intelligent Systems (IIS); and Mathematical Sciences (DMS) announces a solicitation on Multimodal Sensor Systems for Precision Health enabled by Data Harnessing, Artificial Intelligence (AI), and Learning. Next-generation multimodal sensor systems for precision health integrated with AI, machine learning (ML), and mathematical and statistical (MS) methods for learning can be envisioned for harnessing a large volume of diverse data in real time with high accuracy, sensitivity and selectivity, and for building predictive models to enable more precise diagnosis and individualized treatments. It is expected that these multimodal sensor systems will have the potential to identify with high confidence combinations of biomarkers, including kinematic and kinetic indicators associated with specific disease and disability. This focused solicitation seeks high-risk/high-return interdisciplinary research on novel concepts, innovative methodologies, theory, algorithms, and enabling technologies that will address the fundamental scientific issues and technological challenges associated with precision health.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

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Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences
- 47.070 --- Computer and Information Science and Engineering

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 8 to 10

Approximately, 8 to 10 multidisciplinary awards will be made in FY 2020, subject to the availability of funds and quality of proposals.

Anticipated Funding Amount: $6,500,000

Individual projects will be funded up to $750,000 for three years depending on the availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.

Who May Serve as PI:

The Principal Investigator (PI) must be at the faculty level as determined by the submitting organization. A minimum of one PI and one co-PI must participate.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An investigator may participate as PI, co-PI or senior personnel in no more than one proposal submitted in response to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all the co-PIs are participating in only one proposal.

In the event that an individual exceeds this limit, proposals will be accepted based on earliest date and time of the proposal submission, i.e., the first proposal received will be accepted and the remainder will be returned without review. No exceptions will be made.

Proposals submitted in response to this solicitation cannot be duplicates of proposals to any other Federal agency for simultaneous consideration.

A minimum of one PI and one co-PI must participate in a proposal, representing expertise in each of the two areas of hardware and software, for example, sensor systems hardware and AI/ML/MS software. In the introductory section of the proposal, the PI must specify in a separate paragraph how the two areas are integrated in their research approach.

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards. Separately submitted collaborative proposals are not permitted and will be returned without review.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **Full Proposals:**
    - Full Proposals submitted via FastLane: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
    - Full Proposals submitted via Research.gov: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
    - Full Proposals submitted via Grants.gov: *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov* guidelines apply (Note: The *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:**

  Inclusion of voluntary committed cost sharing is prohibited.

- **Indirect Cost (F&A) Limitations:**

  Not Applicable

- **Other Budgetary Limitations:**

  Not Applicable

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

  June 08, 2020

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review criteria apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Standard NSF award conditions apply.

Reporting Requirements:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

Intelligent, interactive, and networked multimodal sensing and imaging systems are a growing part of the biomedical landscape. However, present day multimodal bio-sensing systems for continuous monitoring lack sufficient accuracy, sensitivity, reproducibility, reliability, and precision, and thus quantitative analysis is made more difficult as each sensor modality has its own failure modes and limitations. Some of the challenges in precision health include: correlation of heterogeneous data streams; privacy and security of personal health data; building predictive models; integration of diverse data types; subgroup identification; uncertainty in quantification; and continuous progress in multimodal systems incorporating physical, chemical and biological sensing hardware with existing biomechanical and mechanobiological knowledge such as mechano- and chemo-sensing abilities of cells.

Artificial Intelligence (AI), Machine Learning (ML), and related Mathematical and Statistical (MS) methods offer tremendous opportunities for breakthroughs in precision health by leveraging advances in sensing, imaging, and communication systems hardware and integrating them with data driven model-based learning and decision making. To enhance the effectiveness of treatments for patients based on their molecular, genetic, environmental, biomechanical, mechanobiological, lifestyle and medical history data, currently there is a need for new scientific breakthroughs that permit the incorporation of modularity and learning capabilities at the systems level. To address this need, this solicitation seeks to stimulate the broader community of engineering, computer, mathematical and statistical sciences to achieve bold advances in integrative multimodal sensor systems for precision health that incorporate new smart, functional and reconfigurable materials, device structures and circuits, together with innovative artificial intelligence, machine learning, and related mathematical and statistical methods.

II. PROGRAM DESCRIPTION

The purpose and focus of this solicitation is to stimulate communities from electrical, computer, chemical, biological and mechanical engineering to collaborate with researchers from computer and mathematical sciences, thereby promoting multidisciplinary research that addresses future challenges in precision health using multimodal sensor systems enabled by data harnessing, artificial intelligence, real time learning and decision-making capabilities. The goal of this program is to stimulate non-traditional thinking and new methodologies regarding the issues facing precision health by addressing all three of the following research themes:

1. Design and fabrication of novel multimodal sensor system hardware
2. Integration of multimodal sensor system with novel AI, ML and MS tools to build new predictive models for learning and decision making
3. Characterization and validation of multimodal sensor systems for identification of biomarkers for precision health

Within this intellectual framework, submitted proposals should address all three of the Research Themes identified above. The proposed projects must offer new approaches to bridge the gap between the hardware and software communities involved in multimodal sensor systems with embedded AI/ML/MS research to advance precision health, and thus should have the potential to change the field. The three Research Themes are described in greater depth below:

1. Design and fabrication of novel multimodal sensor system hardware

   This theme encourages design and fabrication of multimodal sensor systems through innovative research on novel functional materials, devices and circuits for sensing or active interrogation of system states, imaging, communications, and computing. Currently existing sensor systems generally operate in discrete formats and are limited in accuracy, selectivity and reliability. Hence, heterogeneous integration diverse sensing modalities and field-adaptive reconfigurable sensor microsystems are of paramount importance for personal health applications. The next-generation of sensor systems for precision health will need to have continuous monitoring of biomarkers from multiple types of sensors (e.g. electrochemical, electromagnetic, mechanical, optical, acoustic, etc.) interfaced with different platforms (e.g. mobile, wearable, and implantable). Combining different sensor modes into a single package will enhance the reliability and validation of measurements due to the increased sensor functionalities, as well as, improved data compatibility and consistency.

   Areas of interest include miniaturized sensor microsystems with integrated signal processing and communication functionalities. Such integrated sensor systems would be capable of generating large amounts of data in real time, which is critical to big data analytics and AI/ML/MS algorithms for decision making and real-time control. To accurately characterize and validate these sensor systems, investigators are encouraged to use the gold standards available to the biomedical community. Another area of interest is multimodal sensor systems with dramatically reduced power consumption to extend battery lifetime and enable self-powered operation, making the sensor systems suitable for wearable and implantable applications. The chemistry of biorecognition and transduction in existing biosensing systems is currently not regenerable, which would be needed for continuous monitoring of analytes. Also of interest is the synthesis of new biorecognition elements that can be reconfigured to target different analytes on-demand, and reset a surface and detach targets bound to the biorecognition elements without complicated fluidic washing steps. Overall, the proposed research should lead to multimodal sensor systems that are sensitive, selective, and stable with rapid response time for continuous monitoring of biomarkers for precision health applications.

2. Integration of multimodal sensor systems with novel AI, ML and MS tools to build new predictive models for learning and decision making

   This theme seeks to integrate multimodal sensing systems with novel AI, ML and MS tools to build innovative predictive models for learning and decision making based on heterogeneous, dependent and stochastic data. This heterogeneous data may include data generated by multimodal sensor systems, patient health records, laboratory generated data (e.g., genomics, proteomics, etc.), existing literature, and clinical trial databases. AI, ML and related mathematical and statistical learning methods can be used to integrate heterogeneous data streams to identify personal health status and aid in the prevention, early detection, and minimally invasive management and individualized treatment of diseases. With the potential for high-density quantitative biomarker data generation, AI/ML/MS should be integrated with multimodal sensor systems to identify combinations of biomarkers associated with specific diseases and disease states with high confidence. Innovative algorithms are needed

to process heterogeneous data with data integration, feature extraction and model selection, and real-time learning and decision-making capabilities. Large data sets are needed to train learning algorithms and enable identification of personal health status.

Challenges for designing and engineering multimodal sensor systems to leverage capabilities in AL/ML/MS include: balancing computing and communications among local, edge or cloud networks; meeting latency and speed requirements; ensuring the privacy and security of personal health data; understanding the role of personalized vs. aggregate data; correlating heterogeneous data streams; integrating diverse data types; identifying subgroups; and building predictive and personal health models for individuals using longitudinal, continuous and spatio-temporal data sets. In addition to the need for more and better data, some general data collection issues must be addressed, including missing data, measurement error, data bias, irregular sampling, poor signal-to-noise ratio, temporal imprecision, data heterogeneity, population heterogeneity, and temporal, spatial and local dependence. New developments in data formatting and data processing are required to automatically format the data independent of the acquisition source and provide it to the end-user for assessment and sharing. This may include de-noising and dimensionality reduction of the raw data and extracted feature space. This theme will support research in fundamental theory, algorithms, and principles for AI, ML, MS modeling and decision-making that will lead to safe, reliable and efficient data-enabled health outcomes.

3. Characterization and validation of multimodal sensor systems for identification of biomarkers for precision health

The key challenges in developing a reliable multimodal biosensing system are linking the hardware with massive data collection, reliable biomarkers selection, and minimizing interference of signals from complex biological samples. Physiological data collected by biosensors often exhibit multiple complicating factors including sparse and irregular sampling, noise, and nonstationarities due to the biofouling of sensing platforms. The presence of one or more of these factors is often sufficient to render current biosensing systems ineffective. Integrated multimodal biosensors with existing biomechaical and mechanobiological models and AI/ML/MS present a great opportunity for overcoming these limitations and for realizing not only a single type of biomarker, but also the combination of biomarker panels associated with the disease with high confidence. Rather than using a shotgun approach monitoring all markers, multimodal sensors should quantify with high accuracy the markers most relevant to a specific disease or disease state.

Since miniaturized sensing systems lack accuracy, AI, ML and related MS methods should be used to account for device to device and sample to sample variation for improving accuracy. ML and MS methods can be used to extract features from the signals generated by the sensing systems and differentiate between noise/biofouling and a true target binding/detection/signalling event. Overall, smart modular and reconfigurable sensor systems with embedded AI/ML/MS for precision health should learn from the collection of data itself and on demand decide what to sense and be able to change measurement parameters, such as the frequency of data collection or detection sensitivity level. It should consume less power leading toward safe, reliable, and efficient data-enabled robust multimodal sensing platforms that can transform the acquired data into information to predict and / or influence future health outcomes of an individual.

The plan for future years is to address these topics through a revised Smart and Connected Health solicitation.

III. AWARD INFORMATION

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 8 to 10

Approximately, 8 to 10 multidisciplinary awards will be made in FY 2020, subject to the availability of funds and quality of proposals.

Individual projects will be funded at up to $750,000 for three years depending on the availability of funds.

Anticipated Funding Amount: $6,500,000 dependent on the availability of funds.

Estimated program budget, number of awards and average award size/duration are subject to the availability of funds.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.

Who May Serve as PI:

The Principal Investigator (PI) must be at the faculty level as determined by the submitting organization. A minimum of one PI and one co-PI must participate.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An investigator may participate as PI, co-PI or senior personnel in no more than one proposal submitted in response to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all the co-PIs are participating in only one proposal.

In the event that an individual exceeds this limit, proposals will be accepted based on earliest date and time of the proposal submission, i.e., the first proposal received will be accepted and the remainder will be returned without review. No exceptions will be made.

Proposals submitted in response to this solicitation cannot be duplicates of proposals to any other Federal agency for simultaneous consideration.

A minimum of one PI and one co-PI must participate in a proposal, representing expertise in each of the two areas of hardware and software, for example, sensor systems hardware and AI/ML/MS software. In the introductory section of the proposal, the PI must specify in a separate paragraph how the two areas are integrated in their research approach.

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards. Separately submitted collaborative proposals are not permitted and will be returned without review.

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via FastLane, Research.gov, or Grants.gov.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.
- Full Proposals submitted via Research.gov: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal and Award Policies and Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov. The Prepare New Proposal setup will prompt you for the program solicitation number.
- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov*. The complete text of the *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: (https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

See PAPPG Chapter II.C.2 for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the PAPPG instructions.

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards. Separately submitted collaborative proposals are not permitted and will be returned without review.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

  June 08, 2020

D. FastLane/Research.gov/Grants.gov Requirements

For Proposals Submitted Via FastLane or Research.gov:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: https://www.fastlane.nsf.gov/a1/newstan.htm. To prepare and submit a proposal via Research.gov, see detailed technical instructions

available at: https://www.research.gov/research-portal/appmanager/base/desktop?_nfpb=true&_pageLabel=research_node_display&_nodePath=/researchGov/Service/Desktop/ProposalPreparationandSubmission.html. For FastLane or Research.gov user support, call the FastLane and Research.gov Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov or rgov@nsf.gov. The FastLane and Research.gov Help Desk answers general technical questions related to the use of the FastLane and Research.gov systems. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: https://www.grants.gov/web/grants/applicants.html. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane or Research.gov may use Research.gov to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in PAPPG Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: https://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Building the Future: Investing in Discovery and Innovation - NSF Strategic Plan for Fiscal Years (FY) 2018 – 2022*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (PAPPG Chapter II.C.2.d(i). contains additional information for use by proposers in development of the Project Description section of the proposal). Reviewers are strongly encouraged to review the criteria, including PAPPG Chapter II.C.2.d(i), prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
    a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
    b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

The proposals submitted in response to this solicitation should address all three of the Research Themes described in the program description. A minimum of one PI and one co-PI must participate in a proposal, representing expertise in each of the two areas emphasizing hardware and software, for example, sensor systems hardware and AI/ML/MS software. The PI must specify in a separate paragraph in the introductory section of the proposal how the two areas are integrated in their research approach.

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by Ad hoc Review and/or Panel Review.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

After programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications. After an administrative review has occurred, Grants and Agreements Officers perform the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process.)

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

VIII. AGENCY CONTACTS

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- Shubhra Gangopadhyay, telephone: (703) 292-2485, email: sgangopa@nsf.gov
- Usha Varshney, telephone: (703) 292-8339, email: uvarshne@nsf.gov
- Aleksandr L. Simonian, telephone: (703) 292-2191, email: asimonia@nsf.gov
- Radhakisan S. Baheti, telephone: (703) 292-8339, email: rbaheti@nsf.gov
- Albert Z. Wang, telephone: (703) 292-7230, email: awang@nsf.gov
- Huixia Wang, telephone: (703) 292-2279, email: huiwang@nsf.gov
- Laurel C. Kuxhaus, telephone: (703) 292-4465, email: lkuxhaus@nsf.gov
- Robert A. Scheidt, telephone: (703) 292-2477, email: rscheidt@nsf.gov
- Wendy Nilsen, telephone: (703) 292-2568, email: wnilsen@nsf.gov
- Balakrishnan Prabhakaran, telephone: (703) 292-4847, email: bprabhak@nsf.gov

For questions related to the use of FastLane or Research.gov, contact:

- FastLane and Research.gov Help Desk: 1-800-673-6188

  FastLane Help Desk e-mail: fastlane@nsf.gov.

  Research.gov Help Desk e-mail: rgov@nsf.gov

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF Grants Conferences. Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on NSF's website.

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at https://www.grants.gov.

ABOUT THE NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

Facilitation Awards for Scientists and Engineers with Disabilities (FASED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter II.E.6 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding

grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at https://www.nsf.gov

- **Location:** 2415 Eisenhower Avenue, Alexandria, VA 22314
- **For General Information** (NSF Information Center)**:** (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**

  Send an e-mail to: nsfpubs@nsf.gov

  or telephone: (703) 292-7827
- **To Locate NSF Employees:** (703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by awardees will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding applicants or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See System of Record Notices, NSF-50, "Principal Investigator/Proposal File and Associated Records," and NSF-51, "Reviewer/Proposal File and Associated Records." Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

Suzanne H. Plimpton
Reports Clearance Officer
Office of the General Counsel
National Science Foundation
Alexandria, VA 22314