Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-209

Proposal Title: Tiny Sensor to Detect Heavy Metals in Fish

Project Manager Information

Name: Tianhong Cui

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: We propose to develop an accurate, cheap and easy-to-use microsensor for detection of heavy metals in fish. It can be used for statewide fisheries management and household fish safety inspection.

Funds Requested: $200,000

Proposed Project Completion: June 30, 2026

LCCMR Funding Category: Small Projects (H)

Secondary Category: Water Resources (B)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Known as Land of 10,000 Lakes, Minnesota has abundant fish resources. People use fish as a food source for dietary protein, B-complex vitamins, trace minerals, and omega-3 fatty acids. However, 26% of the 6,167 Minnesota's Inventory of Impaired Waters listed by MPCA is due to excessive mercury in fish tissue, which can damage our nervous systems and kidneys if it builds up in our body. Young children, developing fetuses, and breast-fed babies are at most risk. Therefore, fish intake for pregnant women and children in Minnesota is strictly limited, even though the omega-3 fatty acids is healthful for them. Although the Minnesota Department of Health published the guideline on fish consumption for different species in waters, mercury levels vary enormously in individual fish. Even within the same fish, mercury levels in different parts can vary significantly. For example, the mercury concentration in fish liver and gills can be tens of times higher than that in flesh. Existing mercury detection typically requires lab-based tests and expensive instruments such as Inductively Coupled Plasma Mass Spectrometry which cannot be reached by fisheries and households. Therefore, developing a small sensor for heavy metals like mercury in fish is urgently needed.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

To solve the mentioned problems, the proposed work is to develop an accurate, cheap, and easy-to-use small sensor for the detection of mercury and other heavy metals such as lead and arsenic in fish. As a field test of this program, we will test heavy metals in different species and sizes of fish in Minnesota waters. Mercury will be of particular interest in this proposed work. Electrochemical microsensors for heavy metal measurement will first be designed and fabricated. Unlike existing electrochemical sensors for heavy metals, the proposed sensor has much higher sensitivity and can detect extremely low concentrations of heavy metal ions by integrating new pyrolyzed glassy carbon material and capillary microfluidics. The sensor will be fabricated by microfabrication technology. The mass fabrication based on this process can reduce the cost of each measurement from thousands of dollars to less than $1. A reusable pretreatment unit for fish tissue and a data collection unit will also be developed and integrated with the sensor. After the lab testing, the system will be brought to lakes and rivers in Minnesota, and fish species are taken from the waters and their heavy metals content will be detected and recorded on site.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

This project aims to solve the great challenge of the heavy metal detection in fish and measure the heavy metal concentration in fish in Minnesota waters. The project has two specific outcomes. Firstly, a solution and product will be provided for heavy metal detection in fish. This allows people to eat fish with greater confidence, while providing the agriculture and fisheries departments with a more economical and easier-to-use tool for the health monitoring and management of fish resource in Minnesota waters. In addition, the field test of the project will provide a more detailed map of Minnesota fish contamination.

Activities and Milestones

Activity 1: Development of an accurate, cheap, and easy-to-use tiny sensor for detection of heavy metals in fish

Activity Budget: $97,807

Activity Description:
We propose to design, fabricate, and evaluate a tiny sensor for heavy metal detection in fish based on electrochemical measurement. The tiny sensor will be designed and fabricated by Prof. Cui's group. There are three key features of the tiny sensor design to ensure good sensing performance. (1) The electrode material for microsensors will be glassy carbon induced by pyrolyzed photoresist at high temperatures. This ensures good stability of electrodes and make it possible to detect an extreme low concentration of mercury due to its low overpotential; (2) A capillary microfluidic channel will be integrated with the electrochemical sensor to enhance mass transfer and further lower the detection limit; (3) A miniaturized blender will be used for pretreatment of fish tissue, and a communication unit will be added to the sensors and transmits testing results to a smart phone. The sensors will be fabricated using microfabrication technology at the Minnesota Nano Center at the University of Minnesota. The fabricated sensors will first be tested and evaluated in laboratory, and the results will be compared with standard method such as Inductively Coupled Plasma Mass Spectrometry. Then the tiny sensor array will be ready for field tests in Minnesota waters.

Activity Milestones:

Description	Approximate Completion Date
Design, fabrication, and testing of tiny heavy metal sensors as testing prototypes in laboratory	December 31, 2024
Characterization, evaluation, improvement, and optimization of the tiny sensors	June 30, 2025
Field tests of the tiny sensors in household fish and evaluate its long-term stability	June 30, 2025

Activity 2: Field test of the heavy metal concentration in different species of fish in Minnesota waters

Activity Budget: $102,193

Activity Description:
This activity seeks to test heavy metals in fish in Minnesota waters. Mercury will be the main detection target heavy metal, and other heavy metals including lead and arsenic will also be detected at the same time. Waters in the twin cities area are proposed to test heavy metals in fish initially, but we will also test fishes in a wider range of waters in Minnesota. Three key questions will be focused on during the field tests. (1) The relationship between the concentration of heavy metal ions in water and the concentration of heavy metals in different species of fish. The sensor can also measure the heavy metal concentration in water, making it possible to study this relationship and establish models. (2) Difference in heavy metal content in different parts of fish species. The concentration of heavy metals in different organs of the same fish will be detected to provide guidance for cooking and eating the fish. (3) Source of the heavy metals in specific waters. The map of fish contamination generated by this project will be compared with the nearby industrial and agricultural distribution to study the source of pollution and provide suggestions for water resources protection.

Activity Milestones:

Description	Approximate Completion Date
Collect fish samples from Minnesota waters for tiny sensors and evaluation & comparison with ICP-MS	December 31, 2025
Field tests in Minnesota waters using heavy metal sensors and generate a fish contamination map	December 31, 2025
Data analysis and system evaluation of the heavy metal sensor	June 30, 2026

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

As the product of this project, a sensor for heavy metal detection in fish will be developed. Patents based on the developed prototypes will be applied for commercialization. The systems will be deployed to waters in Minnesota. Further work will focus on the highly integrated pre-processing and post-processing units and field tests for a broader area. Other federal funding from NSF (i.e., programs including Convergence Accelerator, Growing Convergence Research, etc.), USDA (i.e., the AFRI Foundational and Applied Science Program), EPA, USGS, or private funds will be applied as potential funding sources for further development of heavy metal sensors.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Develop Small and Inexpensive Purification System for Community Drinking Water	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 04e	$425,000
Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 07c	$300,000

Project Manager and Organization Qualifications

Project Manager Name: Tianhong Cui

Job Title: Distinguished McKnight University Professor

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Tianhong Cui is a Distinguished McKnight University Professor at the University of Minnesota. He is a Professor in Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Electrical and Computer Engineering. He joined the faculty of the University of Minnesota in 2003. He is a Fellow of the American Society of Mechanical Engineering. He is also a member of European Academy of Sciences and Arts. Dr. Cui is an international leading expert on micro sensors and advanced manufacturing. He has 368 archived publications in scientific journals and prestigious conferences. He is the founding Executive Editor-in-Chief for a Nature journal, Microsystems & Nanoengineering. He has received awards including the STA & NEDO Fellowships in Japan, the Alexander von Humboldt Fellowship in Germany, the Richard & Barbara Endowed Chair and the Distinguished McKnight University Professorship from the University of Minnesota, the Blaise Pascal Chair Visiting Professorship in France (named after famous French scientist Blaise Pascal), the Distinguished Visiting Fellowship from the Royal Academy of Engineering and the Global Chair at the University of Bath in UK, a recent JSPS faculty fellowship at the University of Tokyo, and numerous best paper awards.

Dr. Cui will serve as PI and project manager, responsible for overseeing the project, all reports, and deliverables. He will supervise one postdoctoral assistant to work on the design, fabrication, and characterization of the tiny sensors to detect heavy metals in fish. He will hold weekly meetings with his advisee to ensure good progress of this proposed work, in addition to some daily technical discussion with his research assistant. He will also collaborate with MPCA and Fond du Lac Environmental Program to collect some fish samples for on-site tests using the tiny heavy metal sensors.

Organization: U of MN - College of Science and Engineering

Organization Description:

The College of Science and Engineering at the University of Minnesota was recently named among the top 10 programs in the nation by Research.com. The Department of Mechanical Engineering at the University of Minnesota is one of the

foremost programs in the United States, serving the state and nation as a leading center of education, research, and innovation.

This work will be performed at the University of Minnesota in the Technology Integration & Advanced Nano/Microsystems Laboratory (TIAN Lab), located in the Mechanical Engineering Building. Professor Cui is the director of TIAN Lab equipped with the state-of-the-art instrument and facility to conduct the proposed research, with a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui and his postdoc to design, fabricate, characterize, and analyze the proposed tiny sensors to detect mercury ions in fish. Some fabrication work will be done in Minnesota Nano Center, a state-of-the-art facility for research in nanoscience and applied nanotechnology. Minnesota Nano Center well maintains these systems, keeps safe operating procedures, and trains students. State support, support from NSF through NNCI, and industry usage allows the Center to offer academic rates, normally less than half of the actual cost of operation.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Tianhong Cui		Principal Investigator			26.9%	0.1		$25,590
Post Doctoral Associate		He is responsible for design, fabrication, and testing of heavy metal sensors.			20.4%	2		$140,344
							Sub Total	**$165,934**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials and supplies for development of heavy metal sensors, including silicon wafers, glass substrate, SU8 polymers, chemicals, etc.	To fabricate and test the heavy metal sensors					$15,066
							Sub Total	**$15,066**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
	Other	40 trips from the University of Minnesota to lakes and rivers in Minnesota	To cover the travel cost for field tests of fish					$2,000
							Sub Total	**$2,000**
Travel Outside Minnesota								

							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
		Scientific Services including cost at Minnesota Nano Center and Characterization Facility at the University of Minnesota	To fabricate and test the heavy metal sensors using their facilities					$17,000
							Sub Total	**$17,000**
							Grand Total	**$200,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	Unrecovered F&A	Support of Mechanical Engineering facilities where research will be conducted.	Secured	$110,000
			Non State Sub Total	**$110,000**
			Funds Total	**$110,000**

Attachments

Required Attachments

Visual Component

File: f51982b5-422.pdf

Alternate Text for Visual Component

Current Technology, New Proposed Technology, and Applications of Heavy Metal Sensors to Fish...

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
UMN SPA Support Letter	d17ce7b1-a66.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Does your project include the design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services, as defined in Minnesota Statutes section 299C.61 Subd.7?

No