

# Earth and Environmental Science Research Community

NNCI Lead Institutions:

MONT, NanoEarth, Nano@Stanford,  
NCI-SW, SERC/Carleton College

Lead PIs:

Trevor Thornton, Mitsu Murayama,  
David Dickensheets



# Research Community: Earth and Environmental Sciences

## A Continuation of Community Building

- 2017 Goldschmidt Conference ↔
- 2018 Goldschmidt Conference ↘
- 2018 NanoEarth Workshop ↙



Science

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HOME > SCIENCE > VOL. 363, NO. 6434 > NATURAL, INCIDENTAL, AND ENGINEERED NANOMATERIALS AND THEIR IMPACTS ON THE EARTH SYSTEM

REVIEW

Natural, incidental, and engineered nanomaterials and their impacts on the Earth system

MICHAEL F. HOHELLA JR. , DAVID W. MOGK , JAMES RANVILLE , IRVING C. ALLEN , GEORGE W. LUTHER , LINSEY C. MARR , B. PETER MCGRIL , MITSU MURAYAMA , NIKOLLA P. QAFOKU , KEVIN M. ROSSO , NITA SAHAJ , PAUL A. SCHROEDER , PETER VIKESLAND , PAUL WESTERHOFF, AND YI YANG 

229 Citations, 10/28/2021



MONTANA STATE UNIVERSITY  
Montana Nanotechnology Facility

Nanotechnology in STEM > Nanoscience in the Earth and Environmental Sciences Workshop

**Nanotechnology in STEM**

- Nanotechnology: an Emerging Science
- Needs and Opportunities
- An Emerging Teaching Opportunity

**Nanoscience in the Earth and Environmental Sciences—Research and Teaching Opportunities**

A Pre-Meeting Workshop In Association with the Goldschmidt 2017 Conference



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Nanotechnology in STEM > Goldschmidt Conference Workshop 2018

**Nanotechnology in STEM**

- Nanotechnology: an Emerging Science
- Needs and Opportunities
- An Emerging Teaching Opportunity
- Evidence-based Teaching Practices

**Nanoscience in the Earth and Environmental Sciences--From Theory to Practice**

A Pre-Meeting Workshop in Association with the Goldschmidt 2018 Conference

Dates: August 11-12, 2018; Location: Boston, MA USA



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Nanotechnology in STEM > NanoEarth Workshop 2018

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- Background Nanoscience Resources for Instructors
- Nanoscience Literature for Earth and Environmental

**NanoEarth Workshop 2018**

Virginia Tech, Blacksburg, VA

April 19-22, 2018

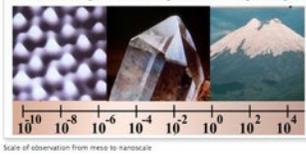
Conveners:  
Michael Hochella, Virginia Tech/PNNL (USA); David Mogk, Montana State University (USA); Jim Ranville, Colorado School of Mines (USA)

(This workshop is by invitation. Details of workshop outcomes will be posted for community use).

Workshop Overview

Participant Workspace (limited access)

The Scale of things. Understanding the World Through Nanoscience

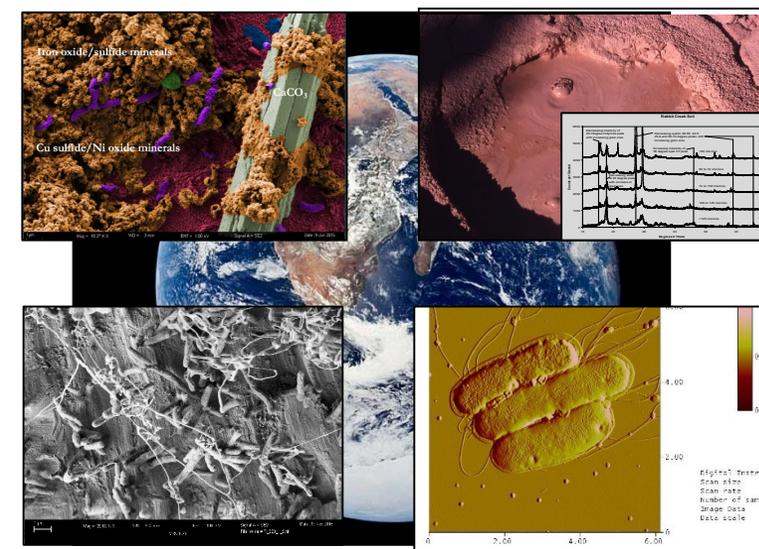
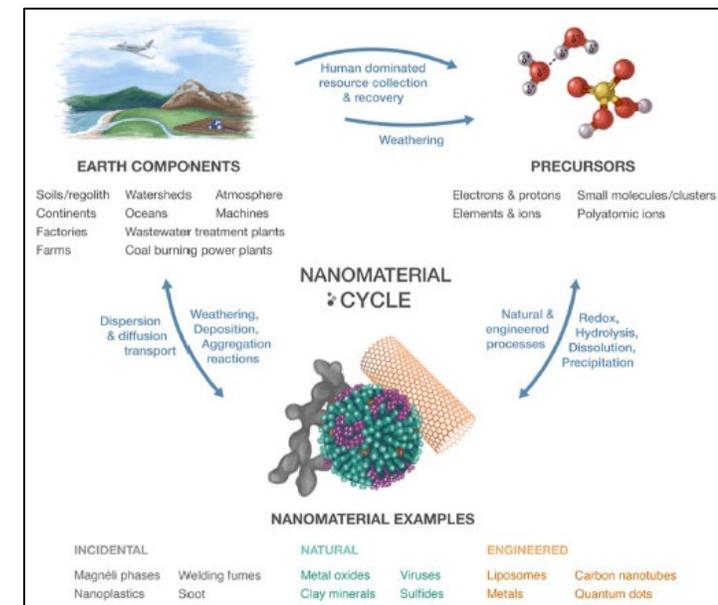


Scale of observation from meso to nanoscale

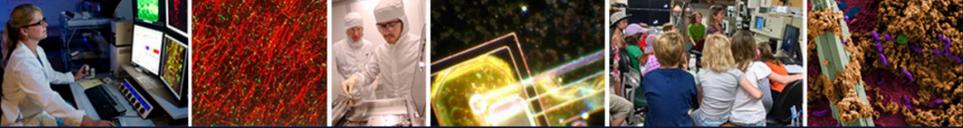
# Research Community on nano-Earth Systems

Nano-ES intersects National Priorities targeting Climate Change; Energy Generation, Storage, Transmission; Clean Water; Environmental and Human Health; as well as NSF Convergence Research

- **Coordinated by MONT, nanoEarth, nano@Stanford, NCI-SW**
- **Annual workshop** with participants from all nano-ES sites, open registration
  - MONT hosted first workshop, Convened virtually in May 2021 **(Y6 of NNCI)**
- Week-long **staff exchange program (start in Y7)**
  - Staff Exchanges will be delayed due to COVID concerns
- NNCI **nano-ES Use/Toolset Inventory (Y6)**
  - In Y6 nano-ES will begin assessing NNCI "landscape" for serving users engaged in earth systems science: tools/expertise available, level of usage, gaps; understand unique needs e.g. for preparation of "dirty" samples
- **Joint REU program** with regular NNCI cross-site virtual activities **(start Y6?)**
  - Each of our sites will have at least one Nano ES REU participant
  - Consult with **GEO-REU Network** run by Val Sloan at the Univ Corporation for Atmospheric Research (UCAR); try to learn "best practices"
  - Facilitate connections for REU faculty in Nano ES
  - Advertise Nano-ES REU across NNCI sites



# Research Community: Earth and Environmental Sciences: 2021 Workshop



**MONTANA STATE UNIVERSITY**  
Montana Nanotechnology Facility

Nanotechnology in STEM > NNCI 2021

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- Nanoscience Literature for Earth and Environmental Science
- Instruments and Analytical Methods Common to Nano
- Registry of Analytical Geochemical Equipment
- Ethics
- National Nanotechnology Coordinated Infrastructure
- Workshops and Events
- NCI Workshop Spring 2021

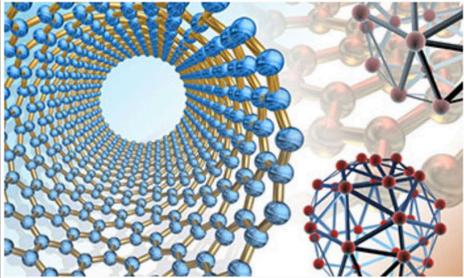
## NCNCI Nanoscience Earth and Environmental Science Research Community Virtual Workshop

May 24–25, with optional 'Office Hours with Experts' on May 26, 2021

Days begin at: 11am ET/ 10am CT/ 9am MT/ 8am PT (Duration: 4 hours each day)

### Workshop Overview

Nanoscience is a frontier area of research that provides abundant opportunities in many different scientific and engineering disciplines. Currently, the Earth and environmental sciences are underrepresented in their participation in this revolutionary field of study, which currently contributes to nano-enabled products worth roughly \$2 trillion annually! There is currently an amazing arsenal of analytical methods that are available to characterize the identity, morphology, composition (bulk and surface), chemical state, atomic structure and related chemical and physical properties of nanoparticles, nanosheets and nanorods. This workshop will focus on practical aspects of using this instrumentation (e.g., AFM and Electron microscopy, surface analysis, fractionation methods, ICP-MS, light-scattering, among many others) in doing nanogeoscience. Topics to be covered include sample collection in the field, sample preparation/preservation, and instrumental data acquisition, reduction, and representation. The workshop will include invited presentations and group discussions to explore modern advances of nanoscience as applied to the Earth and Environmental Sciences. This is an invitation to all Earth and Environmental scientists to join the workshop to learn more about the emerging research and education opportunities afforded by nanoscience, to identify opportunities and needs of conducting nanoscience in the Earth and Environmental Sciences, and to contribute to planning for future research and education initiatives.



## Workshop Goals

- Introduce the geoscience community to new advances and opportunities to do research in nanoscience
- Help participants stay current about data, tools, services, and research related to nanoscience.
- Address the "big science questions" related to nanoscience in the Earth and Environmental Sciences
- Build collaborations; develop research networks to facilitate nanoscience research in the Earth and Environmental Sciences.
- Introduce education outreach efforts for Nano-EES.

## Workshop Program

- 20 invited speakers
- 150 registrants
- Break out "listening" sessions for NNCI to get community feedback
- "Office Hours With Experts", to provide high-quality interactions between NNCI labs and new users to design new research, build collaborations
- Recorded talks and PPTs posted on website<sup>4</sup>

**NCNCI Conveners:** David Mogk, MONT, Tonya Pruitt, NanoEarth, Kate Maher, Nano@Stanford, Paul Westerhoff, NCI-SW Monica Bruckner, SERC/Carleton College

[https://serc.carleton.edu/nnci\\_spring2021/index.html](https://serc.carleton.edu/nnci_spring2021/index.html)

# Research Community: Earth and Environmental Sciences: 2021 Workshop

Virtual format allowed for greater participation and inclusivity; reached a diverse and international audience.

Topical break-out sessions provided important feedback to NNCI leaders.

Interactive “office hours” provided direct information between experts and novices.

- *“The breakout session that I was in was informative as we learned the problems that researches are dealing with.”*
- *“The most valuable part of the workshop, for me, was meeting people with similar research interest and/or whom work at facilities that understand my nano needs. This really made me feel that I finally have a community with which I can discuss ideas, collaborate, and learn.”*
- *“Survey of available instrumentation and methods from different labs. Because one can learn what's available and get up to speed on current methods.”*

[https://serc.carleton.edu/nnci\\_spring2021/index.html](https://serc.carleton.edu/nnci_spring2021/index.html)

## Workshop Facilitation, Communication, Design, and Active Learning Table

Table 7. The mean ratings for each statement targeting workshop facilitation, communication, design, and active learning (n=18)

Statement	Mean Rating
The design of the workshop facilitated exchange of expertise among participants	3.89
The workshop sessions were well facilitated	3.94
The pre-workshop communications gave me the information I needed to learn about and prepare for the workshop	3.94
The workshop events engaged me in active learning related to its goals.	3.59

## Opportunities, ... and Outreach Table

Table 2. The mean ratings for each statement targeting new opportunities, data, implications, collaborations, and outreach (n=18)

Statement	Mean Rating
Introduce the geoscience community to new advances and opportunities to do research in nanoscience through the National Nanotechnology Coordinated Infrastructure (NNCI) program	3.89
Help participants stay current about data, tools, services, and research related to nanoscience	3.94
Address the "big science questions" related to nanoscience: nanomaterials in the Earth system, impacts on biogeochemical processes, characterization of nanomaterials and their chemical properties at the nanoscale, impacts of nanomaterials (natural and incidental) on the environment and human health.	3.78
Build collaborations; develop research networks to facilitate nanoscience research in the Earth and Environmental Sciences.	3.56
Introduce education outreach efforts for nano-ES.	3.67

Listserv established with 225 members

# Expanded Tutorial Webpages on Analytical Methods used in Characterization of Nanoparticles



Nanotechnology in STEM > Instruments and Analytical Methods Common to Nano

<b>Nanotechnology in STEM</b>
Nanotechnology: an Emerging Science
Needs and Opportunities
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<b>Instruments and Analytical Methods Common to Nano</b>
Registry of Analytical Geochemical Equipment
Ethics
National Nanotechnology Coordinated Infrastructure
Workshops and Events

## Instruments and Analytical Methods Common to Nanoscience

### Browse Geochemical Analytical Instruments and Techniques

Each of these pages contains information about each instrument or technique including what it is, fundamental principles, how it works, applications, strengths and limitations, sample preparation, data collection, results, and preparation, and if available, literature and teaching activities/resources.

These resources were originally developed under the Integrating Research and Education project.

#### X-Ray Crystallography

- **Single-crystal X-ray Diffraction**--Christine M. Clark, Eastern Michigan University and Barbara L. Dutrow, Louisiana State University
- **X-ray Powder Diffraction (XRD)**--Barbara L. Dutrow, Louisiana State University and Christine M. Clark, Eastern Michigan University

#### Electron Microbeam

- **Electron Probe Micro-analyzer (EPMA)**--John Goode, University of Minnesota--Duluth

Read more about Geochemical Instruments and



Nanotechnology in STEM > Instruments and Analytical Methods Common to Nano > Auger Electron Spectroscopy

## Auger Electron Spectroscopy

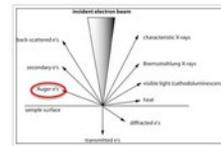
David Mogk, Imaging and Chemical Analysis Laboratory, Montana State University

### What is Auger Electron Spectroscopy

Auger Electron Spectroscopy (AES) is a surface-sensitive analytical method for materials (typically 1-5 atomic monolayers, 3-10 nm depth). AES is widely used in Environmental Sciences (see references below). AES has been applied to catalysis, REDOX, photolytic, and dissolution/precipitation reactions, and detecting all elements except for H and He. Because AES uses a focused electron beam, quantitative analysis of surface composition is possible. Quantitative analysis of surface composition is possible standards. Coupled with a sputter gun, chemical stratigraphy on an atom-by-atom technique that provides information that is complementary to other surface analysis techniques such as Secondary Ion Mass Spectrometry (ToF-SIMS), and "bulk" analytical methods.

### Fundamental Principles of Auger Electron Spectroscopy

Electron-Sample Interactions result in a number of responses such as secondary electron emission and obtain chemical information about materials. The presence of the Auger electron has a very low energy and is readily sorbed by the surface of the near-surface environment of the top few atomic monolayers.



Types of interactions between electrons and a sample.



Nanotechnology in STEM > Instruments and Analytical Methods Common to Nano > X-Ray Photoelectron Spectroscopy

## X-Ray Photoelectron Spectroscopy (XPS; aka Electron Spectroscopy for Chemical Analysis, ESCA)

David Mogk, Imaging and Chemical Analysis Laboratory, Montana State University

### What is X-Ray Photoelectron Spectroscopy?

X-ray photoelectron spectroscopy (XPS) is a surface sensitive, non-destructive technique used routinely to analyze the outermost ~10 nm (~30 atomic layers) of natural and engineered materials. XPS is routinely used to determine a) the composition of material surfaces (elemental identification), the relative abundances of these components on surfaces (semi-quantitative analysis), and c) the chemical state of polyvalent ions by measuring the binding energies of elements which is related to the nature and strength of their chemical bonds. XPS is used to characterize the surfaces of diverse materials such as inorganic compounds (minerals), semiconductors, organic compounds, and thin films and coatings on natural and engineered materials. XPS is used to support research on surface-mediated processes such as sorption, catalysis, redox, dissolution/precipitation, corrosion, and evaporation/deposition type reactions. It is almost always the case that the surface composition and chemistry of materials, measured on the order of a few atomic layers (~10 nm), is different from the "bulk" composition determined by methods such as energy dispersive spectrometry (EDS) with excitation volumes that can extend as much as 3 microns into the material.



Physical Instruments 5600 XPS instrument at the Imaging and Chemical Analysis Laboratory, Montana State University

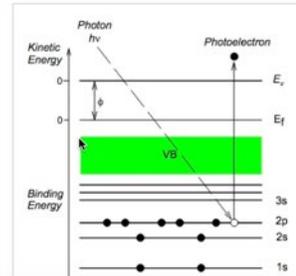
### Fundamental Principles of X-Ray Photoelectron Spectroscopy

XPS is an application of the photoelectric effect (Kleinman 1991; Liska 2009 21) described by Einstein (1905, and was awarded the Nobel Prize in 1921), in which electrons are emitted from atoms in response to impinging electromagnetic radiation. Einstein predicted that photoelectrons would be produced from a material when the energy of impinging photons exceed the binding energy of electrons in that material; the energy is proportional to the frequency ( $h\nu$ ) not the intensity or duration of exposure to the incident electromagnetic radiation. The kinetic energy of an emitted electron is related to the binding energy of each electron, and because atoms have multiple orbitals at different energy states, the resulting response will be a range of emitted electrons with different binding energies (and kinetic energies) thus producing an XPS spectrum. These relations are represented by the equation:

$$E_{\text{kinetic}} = E_{\text{photon}} (h\nu) - E_{\text{binding}} - \phi$$

where  $E_{\text{kinetic}}$  is the kinetic energy of the photoelectron measured by the instrument,  $E_{\text{photon}}$  is the energy of the incident photon (X-ray in this case, which is a known and fixed value),  $E_{\text{binding}}$  is the binding energy of a given electron, and  $\phi$  is the work function, the energy difference between the vacuum energy ( $E_v$ ) level and the Fermi ( $E_f$ ) level of a solid.

Dr. Kai Siegbahn and colleagues from Uppsala University in Sweden recognized the potential of using photoelectrons for chemical analysis (thus, Electron Spectroscopy for Chemical Analysis) and was awarded the Nobel Prize for Physics in 1981 for these contributions.



In aggregate, these "primers" on analytical instrumentation and methods are the most used webpages on the site

[https://serc.carleton.edu/msu\\_nanotech/methods.html](https://serc.carleton.edu/msu_nanotech/methods.html)

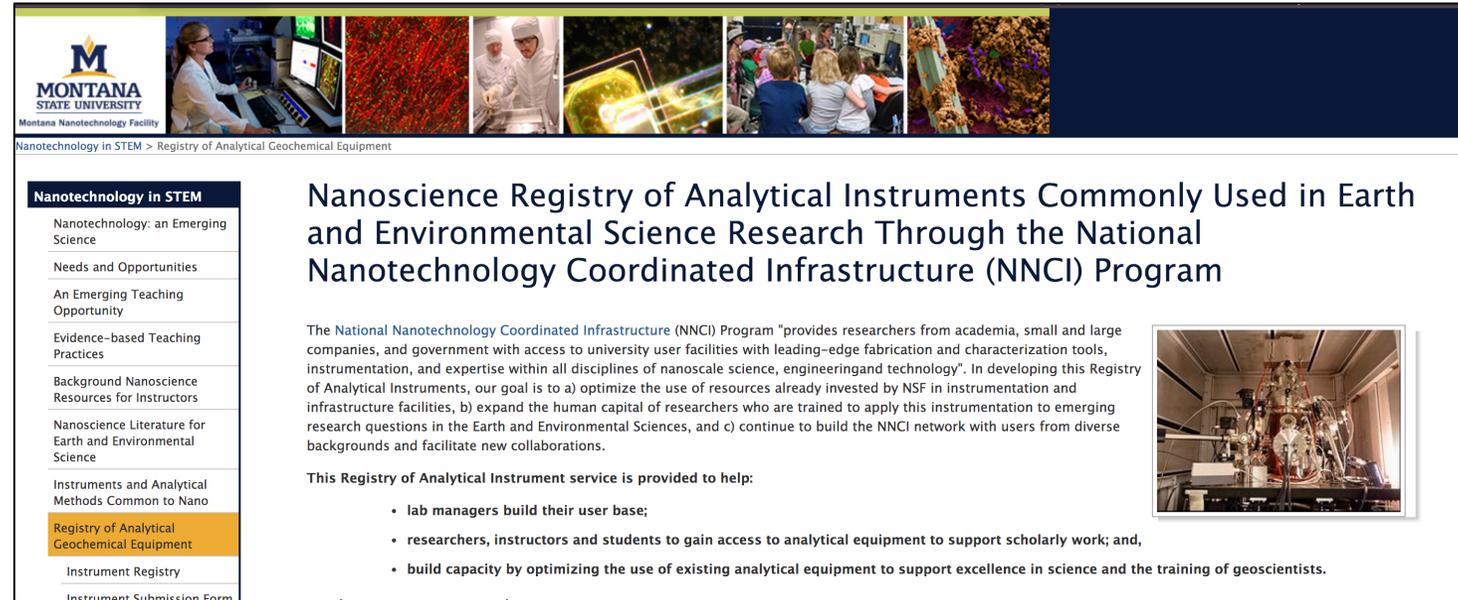


# New: Registry of Analytical Instruments Available in the NNCI Used in the Earth and Environmental Sciences

## This website is a clearing house service:

- For lab managers to build their user base;
- For researchers, instructors, and students to gain access to analytical equipment; and,
- To build capacity by optimizing the use of existing analytical equipment and promote training of Nano-geoscientists.
- NNCI Tools does not represent EES Tool Areas or Sub-Fields
- **This Registry**
  - Is More than a list, a searchable database
  - More robust descriptions and metadata;
  - Focused on EES applications
  - Includes resources beyond NNCI to larger EES community

<https://serc.carleton.edu/242625>



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- Instruments and Analytical Methods Common to Nano
- Registry of Analytical Geochemical Equipment**
- Instrument Registry
- Instrument Submission Form

## Nanoscience Registry of Analytical Instruments Commonly Used in Earth and Environmental Science Research Through the National Nanotechnology Coordinated Infrastructure (NNCI) Program

The National Nanotechnology Coordinated Infrastructure (NNCI) Program "provides researchers from academia, small and large companies, and government with access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology". In developing this Registry of Analytical Instruments, our goal is to a) optimize the use of resources already invested by NSF in instrumentation and infrastructure facilities, b) expand the human capital of researchers who are trained to apply this instrumentation to emerging research questions in the Earth and Environmental Sciences, and c) continue to build the NNCI network with users from diverse backgrounds and facilitate new collaborations.

This Registry of Analytical Instrument service is provided to help:

- lab managers build their user base;
- researchers, instructors and students to gain access to analytical equipment to support scholarly work; and,
- build capacity by optimizing the use of existing analytical equipment to support excellence in science and the training of geoscientists.

### Analytical Instrument Database

The following instruments can be searched by keyword or by using the "narrow the view" function on the right side of your screen. Additional geochemical instruments may be listed in the *On the Cutting Edge* Petrology Geochemical Instrument Browse.

Search:  search

Sort by: **Best Match** Descending SORT

Results 1 - 19 of 19 matches

- An Integrated FFF-splCP-QMS System at the Colorado School of Mines Aquatic Nanoparticle/Colloid Analysis Lab part of NNCI Instrument Collection
- An Integrated FFF-splCP-QMS System at the Colorado School of Mines Aquatic Nanoparticle/Colloid Analysis Lab Skip to Main ContentSkip ...
- Secondary Ion Mass Spectrometer at Arizona State University part of NNCI Instrument Collection
- Secondary Ion Mass Spectrometer at Arizona State University Skip to Main ContentSkip to Navigation Your Account ...
- NanoEarth JEOL IT-500HR at Virginia Tech part of NNCI Instrument Collection
- NanoEarth JEOL IT-500HR at Virginia Tech Skip to Main ContentSkip to Navigation Your Account ...

Refine the Results ↓

- Analytical Instrument Type
- Electron Microbeam 8 matches
- Force Microscopies 1 match
- Mass Spectrometers 1 matches
- Other 2 matches
- Sample Preparation Equipment & Facilities 4 matches
- Other Spectroscopies 2 matches
- Surface Spectroscopies 1 matches
- Whole Rock Analysis 1 match
- X-Ray Diffraction 1 match

User interface: search by instrument type or free text

### Add Your Instrument to the Analytical Instrument Registry

Use the form below to enter your instrument into the database. Please complete a separate entry for each instrument, so that each will appear when the database is searched.

Note that if you navigate away from this page without submitting the form, any work you have completed will be lost and not submitted. Thus, it may be helpful to prepare your responses in Word and then copy and paste them into this form.

Note that the information needs to be uploaded into the database manually, so it will be a few days before your entry appears on our website.

**General Contact Information**

Name of Facility:

Institution:

Carleton College

URL:

**Lab Contact Information**

To make contact about this facility, or for more information about the instrumentation, please contact

Contact Name:

Contact Phone:

Contact Email:

City:

Northfield

State:

Minnesota

Template for lab managers to enter key information

# Example: Instrument Registry Data Sheet

## Auger Electron Spectroscopy System Integrated with EDS and EBSD at the Imaging and Chemical Analysis Laboratory (ICAL), MSU-Bozeman

Montana State University-Bozeman

<https://physics.montana.edu/ical/index.html>

### Contact Information

Sara Zacher (Lab Manager) or Recep Avci (Lab Director)

406 994 4199

[ical@sympa.montana.edu](mailto:ical@sympa.montana.edu)

Bozeman

MT

### Instrument Type

#### Auger Electron Spectroscopy System Integrated with EDS and EBSD

- Field Emission SEM scanning electron microscope--for high resolution imaging down to 5 nanometers
- AES Auger Electron Spectroscopy (or SAM Scanning Auger Microscopy)--for surface analysis of all elements of Z>3 (Li), and surface elemental mapping
- EDS energy dispersive spectrometer--for "bulk" compositional analysis of elements; X-ray elemental mapping
- EBSD detector for in situ phase identification using electron diffraction and determination of crystallographic orientation.



This Phi 710 NanoAuger Probe is a unique analytical system that includes: 1) Field Emission SEM imaging for spatial resolution down to 5 nanometers; 2) AES detector for surficial compositional analysis for atomic monolayers on surfaces, with detection of light elements down to Li; 3) Ar-beam ion gun for "dusting off" surfaces of environmental contaminants and depth profiling capabilities; 4) EDS detector for "bulk" compositional analysis and X-ray elemental mapping of materials, and 5) EBSD detector for phase identification using electron diffraction and determination of crystallographic orientation. These numerous analytical methods can be used in near-real-time to fully characterize in situ the identity, crystal structure and orientation, bulk composition, and surface composition of sub-micron to micron particles. Charge compensation methods are used to analyze insulating materials because conducting coats cannot be applied to AES samples.

#### MODEL:

- Phi 710 NanoAuger Probe

### Application:

#### Application:

Auger Electron Spectroscopy (AES) is a surface sensitive method used to analyze the composition of one or a few atomic layers (~1 nanometer) on material surfaces. All elements of Z>3 (Li) can be detected. Semi-quantitative analyses are obtained using published elemental sensitivity factors. Depth profiles of chemical stratigraphy on material surfaces is obtained using an Ar ion sputter gun. Full spectrum surveys are obtained to determine the inventory of elements on a material surface, and "multiplex" routines are used to scan specific energy windows to focus on specific elements. Micron-scale maps can be obtained to show the distribution of elements on material surfaces. The AES instrument at ICAL is built on a field emission SEM for high resolution imaging, and is also equipped with EDS and EBSD detectors. So near real-time data can be obtained in situ on the same spot for nano-scale morphology, bulk composition, surface composition, atomic structure (to identify the phase) and crystallographic orientation.

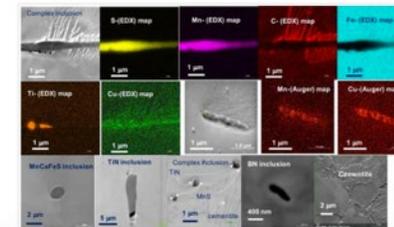
#### Applications include

- Study of surface mediated reactions such as sorption, catalysis, dissolution/precipitation products, REDOX reactions
- Analysis of thin films and surface coatings
- Imaging (size, shape, morphology)
- Crystallographic orientation
- Distribution in matrix (disseminated, aggregated...)
- Textural relations (intergrowths, overgrowths, epitaxial...)
- Interfaces

#### Typical Use:

AES is widely used in research in

- Energy (generation, storage, transfer)
- Microelectronics
- Metallurgy
- Earth and Environmental Sciences (applications are increasing as charge compensation methods are improved).



#### Conditions for Use:

As a regional user facility, ICAL encourages users to acquire training through our Short Courses so that the design and implementation of experiments is done to meet specific user-defined research objectives. Collaboration with ICAL staff is encouraged. Submitted samples can also be analyzed on a contract basis (i.e. lab personnel will do the work). ICAL is also available to do preliminary "proof-of-concept", exploratory experiments, including optimization of instruments to address the defined tasks, data acquisition, and data interpretation to help support future funding and collaboration opportunities.

#### User Fees:

Contact the lab manager for details about user fees. In general, user fees are applied only to actual beam time for instrument use and staff time.

#### Instrument Priorities:

ICAL seeks to accommodate all users who rely on high-quality, rapid turn-around results for both academic research and research and development projects for industrial partners. The lab manager helps coordinate instrument access by: a) researchers with funded research projects; b) collaborations with academic colleagues; c) contract work with industrial partners, and d) education and outreach activities (class demonstrations, class projects, independent study and thesis research projects, etc.). ICAL is a node of the National Nanotechnology Coordinated Infrastructure program, and our mission is to extend use of these instruments to support research across the STEM disciplines in academic and corporate research. Some limited funds are available through the NNCI/MONT NSF award to support pilot research projects. Please visit <https://nano.montana.edu/> for details.

#### Remote Use:

Remote operation is not directly possible for any of the ICAL instruments. But in response to the COVID lockdowns, we have implemented use of real-time video delivery to allow external users to observe analysis of their samples and to provide for direct interaction and decision-making as the experiments proceed.

#### Sample Preparation:

Samples are typically analyzed "as received". The AES operates under Ultra High Vacuum (UHV) so volatile materials should be avoided. Samples are commonly mounted on a conducting material such as indium, a Si wafer, or TEM-style Cu grid. Samples are typically exposed to a gentle Ar beam application to remove sorbed environmental layers.

#### Standard Collections/Lab Blanks:

Standardization for AES analysis is difficult and not commonly done.

#### Software:

AES data collection provides retrospective analysis as every pixel of the image contains the full Auger spectrum.

#### Educational Use:

Class demonstrations are available for undergraduates. Class demonstrations are available for K-12 Undergraduate student research projects are invited. Graduate student research projects are invited. Tutorials and other educational materials related to the lab are available. ICAL routinely offers class demonstrations and supports course projects across the STEM disciplines. We encourage interested users to take our 10 hour short courses in the operation of each instrument to become independent users of this facility as part of our professional training program.

# Thank you!