Technologies for characterizing critical minerals in solid mining and mineral processing waste at legacy sites

EMRTAI - An Initiative Supported by the Environmental Protection Agency Office of Mountains, Deserts, and Plains and Office of Land and Emergency Management

June 9, 2026

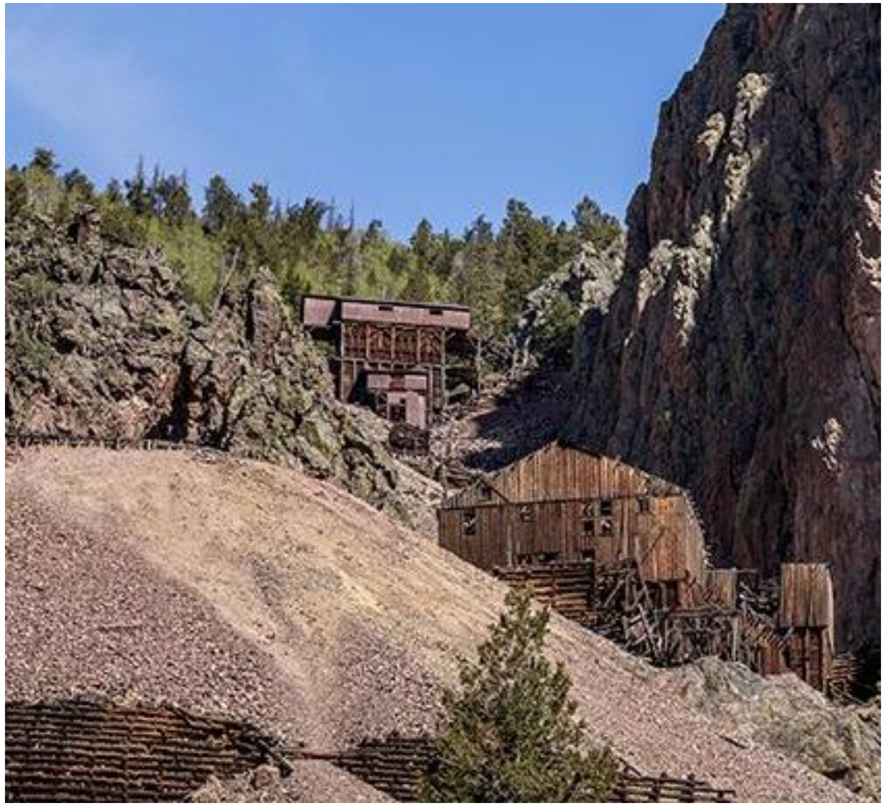
Deepti Krishnan Nair, Battelle EMRTAI Technology Assessment Manager
Dr. Jana Heisler-White, Battelle EMRTAI Project Manager
Benjamin Simes, EPA Project Officer
Dr. John McKernan, EPA Quality Assurance Manager

EMRTAI

Environmental Monitoring and Remediation Technology Assessment Initiative

EMRTAI Overview

- Approximately **100 MMP sites on EPA Superfund National Priority List (NPL)** undergoing remediation
- Mining produces large amounts of *waste* material
- Mine waste can serve as feedstock for minerals (unconventional source)
- Recovery of minerals can be incorporated into remedial action plans to promote sustainable materials management, and potentially expedite site cleanups and offset costs



EMRTAI is operated as a cooperative agreement between Battelle Memorial Institute and the EPA OLEM/OMDP

EMRTAI Overview

EMRTAI is the Environmental Monitoring and Remediation Technology Assessment Initiative

Goal: To **drive innovation** and facilitate dialogue through **technology assessments** that produce data for informed decisions surrounding the **identification and recovery of critical minerals from mine waste** at legacy mining and mineral processing sites **during site remediation**.

Chat piles at Tar Creek, Oklahoma

EMRTAI Objectives

Objectives:

(1) To conduct **technology assessments** that will produce credible performance data to accelerate technology implementation for the benefit of diverse stakeholders

(2) To advance the Initiative through **stakeholder engagement**

(3) To **collaborate** with mining and mineral processing site owners, federal, state, and local stakeholders, and communities where technology assessments may occur

(4) To create a **community of technology developers and users** focused on **resource recovery while reducing risk to human health and the environment**

Critical Minerals

Definition: “essential to the economic or national security of the U.S., have a supply chain of which is vulnerable to disruption, and serve an essential function in the manufacturing of a product… the absence of which would have significant consequences for the economy or national security” (Energy Act of 2020)

Unconventional Sources (e.g., mine wastes):

Building a U.S. supply chain to meet current and projected needs for critical minerals is a federal priority (Executive Order 14017).

Infrastructure Investment and Jobs Act directed the USGS to assess potential critical mineral resources in mine wastes

Source:
Federal Register. 2025. Final 2025 List of Critical Minerals *https://www.federalregister.gov/documents/2025/11/07/2025-19813/final-2025-list-of-critical-minerals*.
Presidential Executive Order. 2025. Immediate Measures to Increase American Mineral Production. White House, March 20.

Element	Category	Element	Category
Aluminum	TAL, CM	Mercury	TAL
Antimony	TAL, CM	Neodymium	CM
Arsenic	TAL, CM	Nickel	TAL, CM
Barium	TAL	Niobium	CM
Beryllium	TAL, CM	Palladium	CM
Bismuth	CM	Platinum	CM
Boron	CM	Potassium	TAL
Cadmium	TAL	Praseodymium	CM
Calcium	TAL	Rhenium	CM
Cerium	CM	Rhodium	CM
Cesium	CM	Rubidium	CM
Chromium	TAL, CM	Ruthenium	CM
Cobalt	TAL, CM	Samarium	CM
Copper	TAL, CM	Selenium	TAL
Dysprosium	CM	Scandium	CM
Erbium	CM	Silicon	CM
Europium	CM	Silver	TAL, CM
Gadolinium	CM	Sodium	TAL
Gallium	CM	Tantalum	CM
Germanium	CM	Tellurium	CM
Gold	CM	Terbium	CM
Hafnium	CM	Thallium	TAL
Holmium	CM	Thulium	CM
Indium	CM	Tin	CM
Iridium	CM	Titanium	CM
Iron	TAL	Tungsten	CM
Lanthanum	CM	Uranium	CM
Lead	TAL, CM	Vanadium	TAL, CM
Lithium	CM	Ytterbium	CM
Lutetium	CM	Yttrium	CM
Magnesium	TAL, CM	Zinc	TAL, CM
Manganese	TAL, CM	Zirconium	CM

Technology Assessment Program

Structured, peer-reviewed process

Benefits to Technology Developers and Vendors

- Access to independent third-party evaluation
- Recognition resulting from assessment
- Data to support technological advancement (e.g., de-risking)

Benefits to Users

- Confidence in technology selection
- Credibility of test data
- Openness of testing process

Technology Assessment Program

1. Promoting technological advancement

- Two types of technologies
  - Field characterization/monitoring
  - Mineral recovery

2. Producing credible, quality assured performance data

  - Advance technologies to commercialization
  - Support implementation

Technology Assessment Program

Calls for Applications (October 2024, Sept 2025, March 2026)

1. Technologies to recover critical minerals from mining-influenced water
2. Technologies to characterize critical minerals in solid mining and mineral processing waste
3. Technologies to recover critical minerals from solid mining and mineral processing waste

Characterize Critical Minerals in solid mining and mineral processing waste

1. Accept technology for evaluation
2. Development of a Quality Assurance Project Plan (QAPP) for a Technology Assessment
3. Development of a testing plan specific to the technology vendor
4. Sample preparation for the Technology Assessment
5. Conduct Technology Assessment
6. Report and Performance Statement development

A technical panel engaged for QAPP and technology assessment report review

(Stakeholder experts from government, universities, consultancies, and industry)

Characterization Technology Assessments

Technology Assessments - Credible, Quality Assured, Transparent, Consistent

Technical Panel Engagement

- Robert Gregory, *University of Wyoming*
- Cecilia Lazo-Skold
- Karla Lesli, *Parsons*
- Virginia McLemore, *New Mexico Bureau of Geology*
- Andrew Nicholson, *Integral Consulting*
- Matt Noerpel, *U.S. Environmental Protection Agency, Office of Research and Development*
- Karina Rogers, *HDR, Inc*.
- Anna Wendt, *U.S. Department of Energy, National Energy Technology Laboratory*

Quality Assurance Project Plan (QAPP) for Characterizing Concentrations of Critical Minerals in Solid Mine Waste using Handheld X-Ray Fluorescence

Technology Assessment Testing Plan for Hitachi-MET8000 Expert Geo

Technology Assessment Report for Hitachi X-MET8000 Expert Geo
Technology Performance Statement for Hitachi X-MET8000 Expert Geo

Characterization Technology Assessments

Current Challenge: Concentrations of critical minerals in tailings, waste rock, chat, slag, contaminated soils/sediments, etc. at legacy sites are generally unknown.

- Existing data on contaminant metals that are also critical minerals
- Ongoing efforts to characterize existing waste materials for critical minerals
- Need for rapid, cost-effective screening of sites to understand the potential use of waste as a resource

Solution: Field Portable X-ray Fluorescence

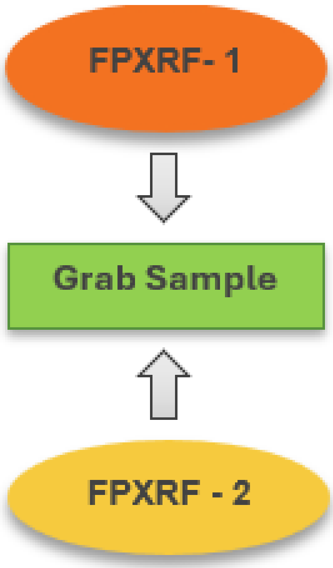
Scenarios and Applications for Characterization Technology

Three Use Cases for solid MMP waste:

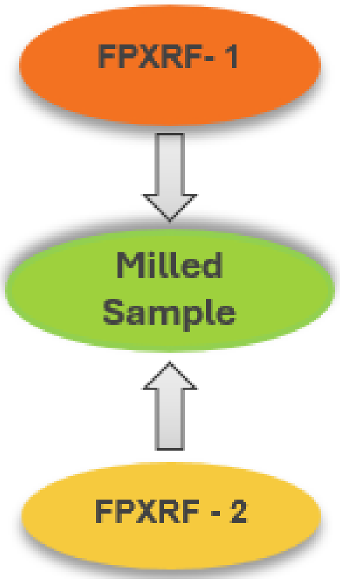
- Use Case 1: Screening of grab samples
- Use Case 2: Screening of milled samples
- Use Case 3: Enhanced screening of milled samples using site-specific standards

Characterization Technology Assessments

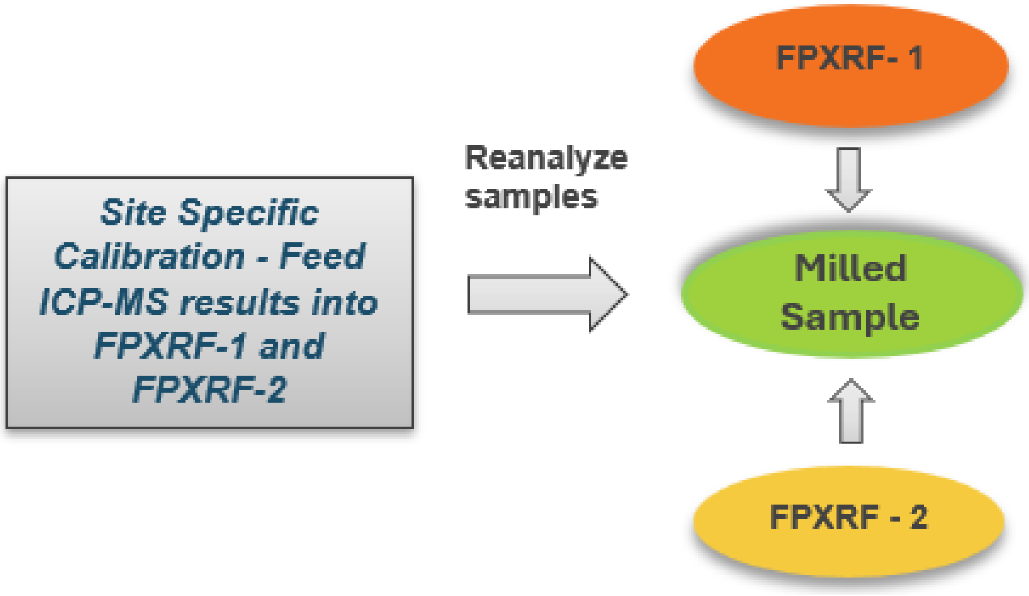
Scenarios & Applications for Characterization Technology: Field Portable XRF



Use Case 1: Screening of grab samples of solid mining waste



Use Case 2: Screening of milled samples of mining waste



Use Case 3: Enhanced screening of milled samples of mining waste using site-specific standards

Baseline Sample Collection

EMRTAI has characterized waste materials for five sites. Data are posted online. This is expected to grow to 10 by the end of 2026

Sites used for the Hitachi Technology Assessment

- Formosa Mine, Riddle, Oregon
- Bonita Peak Mining District, Colorado
- Tar Creek, Ottawa County, Oklahoma

Chat samples from Tar Creek, Oklahoma

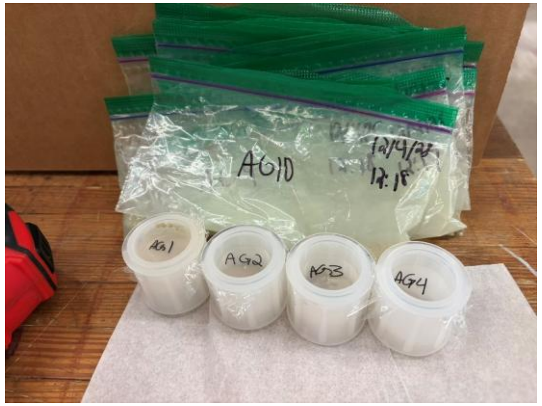
Tailings samples from Bonita Peak Mining District, Colorado

Waste rock from Formosa Mine, Oregon

Characterization Technology Assessments

Hitachi Technology Assessment

- Sample preparation- waste rock and tailings
- Shipped samples to Hitachi facility in Chicago
- Battelle onsite for 3 days to observe the Technology Assessment
- Shipped the samples back to Battelle facility for lab analysis



Technology Assessment Procedure

Grab sample analysis → Milled sample analysis → Milled sample analysis with site-specific calibration → Intra unit repeatability

Characterization Technology Assessments

The TA will evaluate seven parameters:

- Comparability
- Accuracy
- Precision
- Detectability
- Intra-unit repeatability
- Inter-unit repeatability
- False positives and negatives

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Barium	TAL	Niobium	CM
Beryllium	TAL, CM	Palladium	CM
Bismuth	CM	Platinum	CM
Boron	CM	Potassium	TAL
Cadmium	TAL	Praseodymium	CM
Calcium	TAL	Rhenium	CM
Cerium	CM	Rhodium	CM
Cesium	CM	Rubidium	CM
Chromium	TAL, CM	Ruthenium	CM
Cobalt	TAL, CM	Samarium	CM
Copper	TAL, CM	Selenium	TAL
Dysprosium	CM	Scandium	CM
Erbium	CM	Silicon	CM
Europium	CM	Silver	TAL, CM
Gadolinium	CM	Sodium	TAL
Gallium	CM	Tantalum	CM
Germanium	CM	Tellurium	CM
Gold	CM	Terbium	CM
Hafnium	CM	Thallium	TAL
Holmium	CM	Thulium	CM
Indium	CM	Tin	CM
Iridium	CM	Titanium	CM
Iron	TAL	Tungsten	CM
Lanthanum	CM	Uranium	CM
Lead	TAL, CM	Vanadium	TAL, CM
Lithium	CM	Ytterbium	CM
Lutetium	CM	Yttrium	CM
Magnesium	TAL, CM	Zinc	TAL, CM
Manganese	TAL, CM	Zirconium	CM

Characterization Technology Assessments

Key Questions

1. What is the ***degree of association between FPXRF and ICP-MS measurements*** made on the same set of milled samples, and is this association statistically significant?
   - Based on sample type, sites
2. What effect does ***preparing (milling) the sample have on sample measurements*** taken using FPXRF, and is this effect statistically significant
   - Based on sample type
3. Does the association between FPXRF and ICP-MS measurements made on milled samples differ if the FPXRF is ***site-calibrated versus uncalibrated***?
   - Based on calibration types
4. How does the ***ability to detect the presence of a particular chemical*** in grab or milled samples differ between FPXRF and ICP-MS?
5. What is the value of the coefficient of variation associated with ***inter- instrument variability*** for the FPXRF technology?
6. What is the value of the coefficient of variation associated with ***intra-instrument variability*** for the FPXRF technology?

Characterization Technology Assessments

Parameters	Purpose	Statistical Comparisons of Interest	Mathematical or Statistical Parameter
Comparability	Assess the extent to which two sets of measurements are comparable.	Grab FPXRF vs milled FPXRF Grab FPXRF vs ICP-MS Milled FPXRF vs ICP-MS Site-specific calibrated FPXRF vs ICP-MS Site-specific calibrated FPXRF vs milled FPXRF Site-specific calibrated FPXRF vs grab XRF	Tests of association within the ANOVA; Pearson correlation coefficient (R^2) if association is linear.
Accuracy	Comparison of values	Grab FPXRF vs ICP-MS Milled FPXRF vs ICP-MS Site-specific calibrated FPXRF vs ICP-MS	Standard errors reported in the ANOVA model fittings, expressed as coefficients of variation.
Intra-unit reproducibility	Quantification of measurement repeatability	Repeated measurements taken by the same unit on the same (or identical) samples.	Coefficient of variation
Detectability	Compare the reported detection and reporting (quantification) limits between FPXRF and ICP-MS Determine if the extent of detectability (i.e., detected versus not-detected outcomes) differs significantly between FPXRF and ICP-MS	Observational comparison and interpretation of the ranges of these limits and how the underlying technology of the methods affects these ranges. Test of association in how the two methods result in yielding a detected outcome when testing milled samples	Table of detection and reporting limits for both technologies. Categorical tests of association (e.g., chi-square; Fisher's exact test) to assess statistical association in detectability between the two methods
Inter-unit reproducibility	Test the level of agreement in measurements taken on the same samples between the two FPXRF instruments used in the TA.	Comparison between the two tested FPXRF instruments.	Paired t-test. Descriptive statistics and plots applied to the paired differences.
False positives and negatives	Additional parameter to test the accuracy	2x2 contingency table analysis of the following: Grab FPXRF vs ICP-MS Milled FPXRF vs ICP-MS	Sensitivity, specificity, positive predictive value, negative predictive value

Characterization Technology Assessments

Three Technology Assessments for Characterization of CM in solid mine waste

- Hitachi – TA completed in April 2026
- Spectro scheduled for July 2026
- Evident – TBD – Fall 2026

April 2026	TA #1: Hitachi assessment conducted
July 2026	TA #1: Hitachi Report and Performance Statement planned TA #2: Spectro SPECTROSCOUT assessment
September 2026	TA #3: Evident Scientific XRF assessment
October 2026	TA #2: Spectro SPECTROSCOUT Report and Performance Statement planned
December 2026	TA #3: Evident Scientific XRF Report and Performance Statement planned

Questions

Get Involved!

Outreach and Stakeholder Engagement

- Quarterly Stakeholder Meetings
- Participation in Technical Panels
- Join the email list for bi-monthly updates
- Follow us on LinkedIn

EMRTAI

Environmental Monitoring and Remediation Technology Assessment Initiative

If you are a technology vendor or developer, we are interested in talking with you about assessment opportunities under EMRTAI.

Benjamin Simes
EPA Program Officer
EPA/OLEM/OMDP Washington, DC
Simes.Benjamin@epa.gov

Dr. John McKernan
EPA Co-Program Manager
EPA/ORD Cincinnati, OH
McKernan.John@epa.gov

Dr. Jana Heisler-White
Battelle Project Manager
Battelle Memorial Institute,
Columbus, OH
heislerwhite@battelle.org

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