UNM Community-Partnered Metals Research Program

Multi-generational environmental, health, & intervention research with Indigenous communities impacted by abandoned uranium mine waste

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DiNEH Project
Navajo Birth Cohort Study/Environmental influences on Child Health Outcomes
Center for Native Environmental Health Research Equity

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Your Environment. Your Health.
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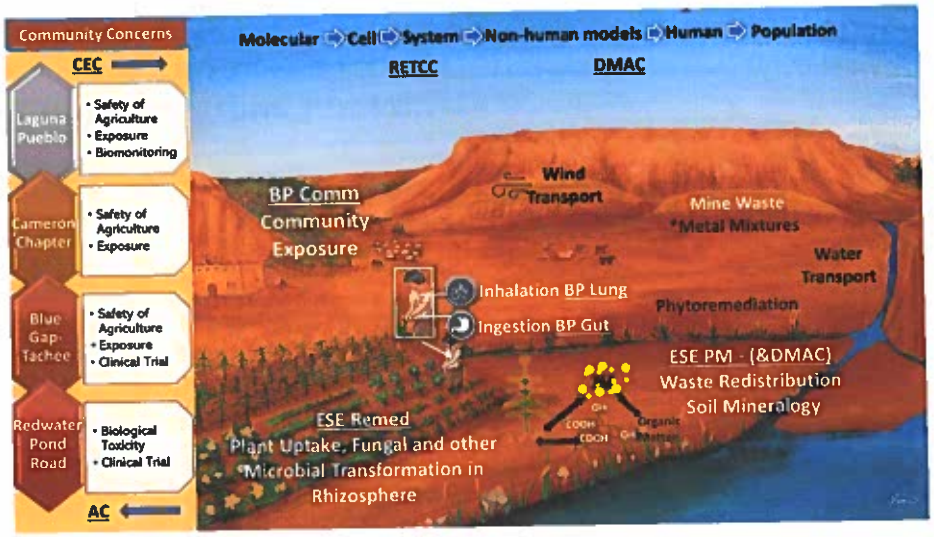
Research summarized here reflects work conducted collaboratively in partnership with communities and tribal partners from Navajo Nation and the Pueblo of Laguna in response to community concerns about the health and environmental impacts of living in proximity to abandoned uranium mines.

Work began in 2005 and is ongoing through the Centers described below

DiNEH Project (RO1) 2005 - 2013	First research to examine community impacts on health in partnership with request from 20 chapters in and adjacent to Eastern Agency of Navajo Nation (NIEHS)
NBCS & NBCS/ECHO 2010 - ongoing	Responsive to congressional mandate to community concerns from DiNEH Project: "What is exposure doing to the health of future generations?" (CDC, NIH-OD)
Center for Native Environmental Health Research Equity 2015 - ongoing	Comparative community partnered study with Navajo, Sioux, and Apsaalooke to examine ecosystem and health effects in tribes from distinct language groups and cultures impacted by mine waste, combined effects of microplastics and organic emissions from waste combustion. (NIEHS, USEPA, NIMHD)
UNM METALS Superfund Research and Training Center (2017-2022). Renewal for Phase 2 (2022-2027)	Multidisciplinary and transdisciplinary team science research partnership with Navajo and Pueblo communities to examine environmental and health risks from mine waste to communities and design interventions to reduce and reverse impacts (NIEHS)

Model underlying the body of research summarized here

- Research began with community questions on exposure and toxicity
- Results reflect a transdisciplinary team of toxicologists, engineers, mineralogists, geographers, modelers, social scientists, immunologists, statisticians, community members, data scientists, indigenous leaders, and others
- Health studies incorporate population exposure-outcome associations, validated in controlled laboratory studies
- Goal of risk reduction informed by knowledge of mechanisms of toxicity and environmental mobility
- Series of interventions include clinical trial reversal of efffects, warning systems, short and long-term environmental immobilization, removal strategies with community goals as drivers



BP (Biological Projects)
ESE (Environmental Science and Engineering
DMAC (Data Management and Analysis Core)
RETCC (Research Experience and Training Core to support the next generation of researchers)
CEC (Community Engagement Core) AC (Administrative Core)
Artwork developed by staff artist-in-residence Mallery Quetawki – Zuni Pueblo

Lewis J, Hoover J, MacKenzie D. Mining and Environmental Health Disparities in Native American Communities. Curr Environ Health Rep. 2017 Jun;4(2):130-141. doi: 10.1007/s40572-017-0140-5. Review. PubMed PMID: 28447316; PubMed Central PMCID: PMC5429369. https://www.ncbi.nlm.nih.gov/pubmed/28447316/

Summary of exposure and health results

(recap of Sept 2021 presentation to the committee, references in that presentation (attached))

- **Exposures** – based on urine and other metals in urine and blood & surveys
  - **Significantly higher than in US** population: 3-5 times the number of individuals with highest exposures (>95th %ile)
  - Some **children born with uranium** greater than that adult 95th %ile
  - **Children** continue to show **increasing exposures over first 5 years** of life to uranium and other metals including arsenic
  - Children's exposure **match adults by age 4**
  - Evidence for exposures from **multiple environmental sources** including **air and water, episodic, mixtures vary with time**

- **Health outcomes** of increased likelihood with exposure
  - **Cardiovascular disease** and **hypertension**
  - Increased likelihood of having **multiple chronic diseases** including cardiovascular & kidney disease, diabetes.
  - 2-3 fold increase in preterm birth in mothers exposed to metal mixtures in community exposures
  - Increased **immune dysfunction, chronic inflammation**, and markers associated with **autoimmune disease**
  - **DNA damage** most sensitive outcome reported for both uranium and arsenic – inhibition repair
  - Increase likelihood of neurodevelopmental delays, especially in early language development

Ongoing clinical trial showing potential to reverse some effects even with higher exposures!!!!

Summary of environmental mobility investigations

(recap of Sept 2021 presentation to the committee, references in that presentation (attached))

Air

- Waste now weathered to nano-sized particles, readily move in wind, reach deep lung if inhaled.
- Mineralogy (i.e. mixture) varies by site
- Redistribution by wind, uncertainty remains due to minimal met data available

Water

- Mobility influenced significantly by pH, Ca, and Bicarbonate (U and As)
- Microbial communities, including fungi, also influence mobility

Plant uptake

- Uranium soil-to-roots and roots-to-shoots visibly increases with calcium concentration in soil
- Fungi in the root-soil interface greatly influence uptake as well

Current investigations focused on using these results to investigate innovations in remedial actions!

Site-specific risks vary

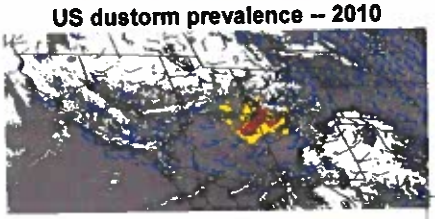
Influenced by local geochemistry/mineralogy, land use

Current activities

- Work to reduce uncertainties in redistribution models
  - Accessing finer-grained remote sensing data on air movement
  - Understand future impacts of climate change with > wind, > drought → increased mobilization
- Identify areas of greatest risk – e.g. agricultural plots, characterize current soil, water, plant characteristics
  - Think broadly on risk reduction ->interventions from warning, to immobilization, to removal
  - Current risk reduction to replace health/environmental risk does NOT replace ultimate removal
- Work using precautionary principle approach
  - Err on side of protecting health in the face of uncertainty
- Understanding implications of "background"
  - Not rationale for additional pollution or more lax clean-up
  - Higher background risk should lead to more conservative decisions, not define sacrifice zones

Redistribution with time (35-80 yrs since deposition for uranium)
Patterns likely to change with climate change ↑drying & ↑wind

US dustorm prevalence -- 2010

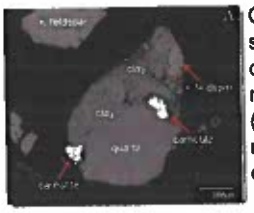


Significant weathering → mineralogically variable nanoparticulates

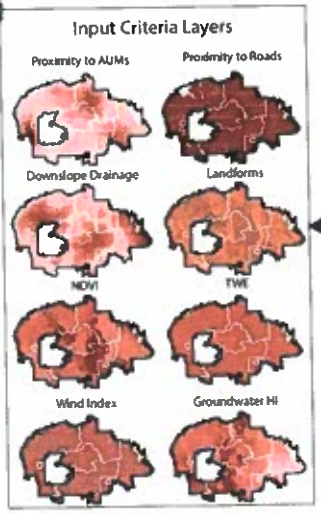
Readily lofted, transported by winds, & inhaled – toxicity not fully understood

Work with Navajo Nation EPA to inform land use & remdiation decisions

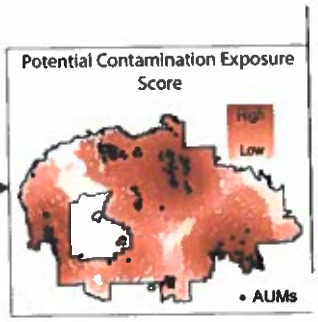
Dust storm New Mexico 2014



Clusters of soluble carnotite nanoparticles (U/V) on respirable clay particle



GIS Modeling & Analysis (GIS-MCDA)



Limited local met data being addressed with additional stations
long-term, using finer scale remote sensing data short-term, improving prediction – fit ~.7 (NURE, research samples)
3 new stations planned – location driven by uncertainty in model

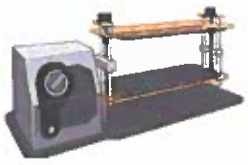
Lin, et al., 2020. Environmental Science and Pollution Research, 27, 30542-30557.

Can we use Natural mineral properties for remediation?

Removal of aqueous uranium(VI) and arsenic(V) with hydroxyapatite precipitation and limestone

Bench Study 1 (pH at 3 and 7 for 31 days):
50 µM **U** + 50 µM **As** + 1 mM **PO_4** + 3 mM **Ca**
with and without **limestone** (1g/L)

Bench Study 2 (pH increased from 7 to 11):
50 µM **U** + 50 µM **As** + 2 mM **PO_4** + 10 mM **Ca**
with **limestone** (1g/L)

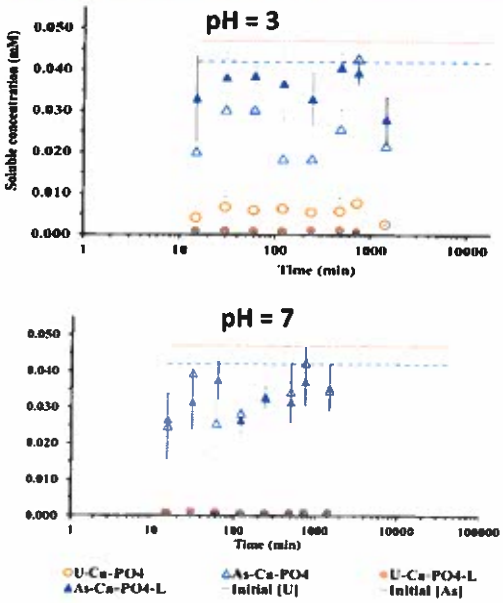


Samples taken continuously for 31 d

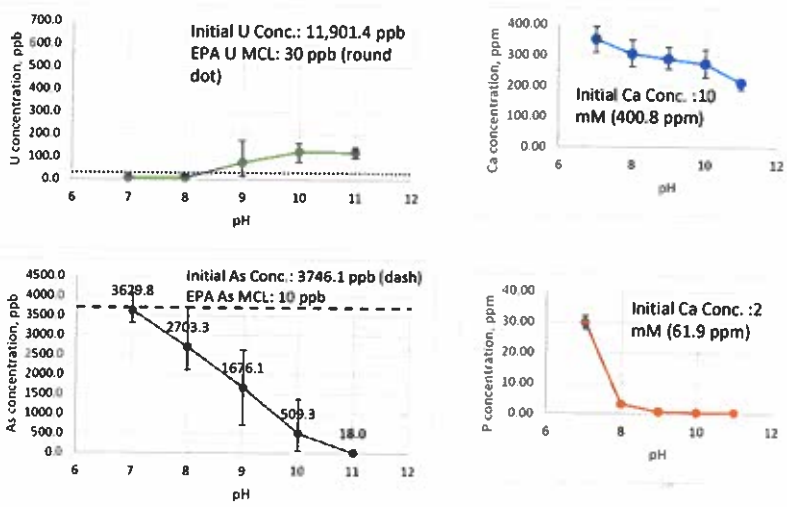
Created by Biorender.com

1. **ICP-OES, ICP-MS:** As and U concentrations in the solution
2. **Microprobe/Powder XRD/SEM-EDX:** Solid sample characterization

Bench Study 1 (pH at 3 and 7, for 31 days):



Bench Study 2: Removal of U and As as function of pH (limestone and Ca-P precipitation)



- pH 3, Ca and P ->limited precipitation, removal depended on limestone adsorption and precipitation of Ca, U, As, and P. limestone potentially increased (Ca)-U-P nano precipitation but limited effect on As.
- pH 7, U greatly removed in both groups, visible Ca-P precipitation. As concentrations were still high.
- Ca and P increased in **Bench Study 2** to improve As removal with a **higher pH** range as Ca also precipitates.

Takeaway Message

Objectives of experiments:

- ***To develop cost-effective remediation approaches that can use ubiquitous minerals, mainly limestone components, in natural environments to remove U and As.***

Current results:

- ***Bench Study 1: U effectively removed by forming U-P precipitation at low pH, enhanced by limestone.***
- ***Bench Study 2: concentrations of Ca and P, Ca-P solid of hydroxyapatite (HAP, $Ca_5(PO_4)_3(OH)$).***
  - ***Precipitated between pH 7 and 9.***
  - ***pH 9, 98.8.% of U was removed by forming U-P precipitation, and 90.5% As removal by HAP adsorption effect.***
  - ***Higher pH could cause a part of U to remobilize by forming U-CO_3 complexes.***

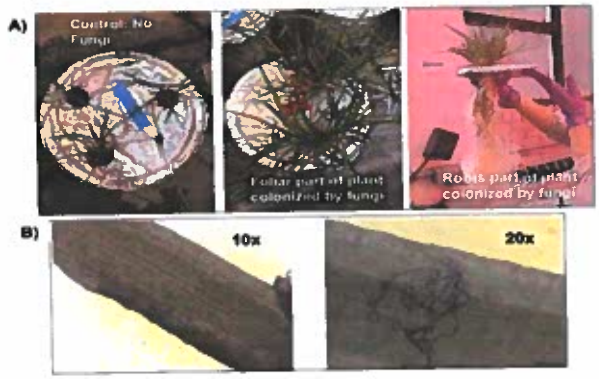
High dissolved Ca and abundant limestone found in our study sites ***suggest simultaneous removal of U and As*** *will be* ***very likely*** *to achieve around* ***pH 9 with supplementary phosphate.***

Collaborators: Jose Cerrato, Han Hua

Can fungal bioreactors immobilize and remove toxic metals from soil and water???

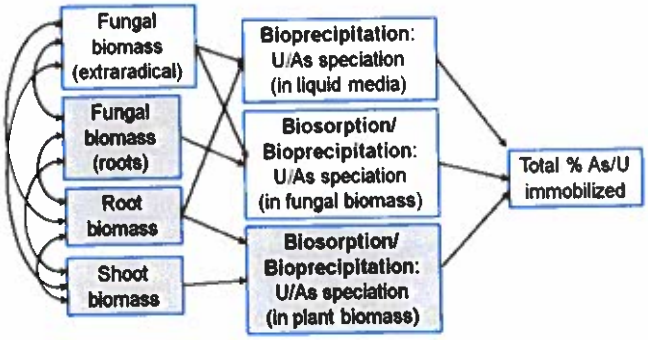
- The Rudgers' lab (Sevilleta LTER) maintains a Western US fungarium consisting of 1,033 fungal isolates collected from 24 sites in the Western states, archived at -80°C and in sterile water.
- Isolates of taxa known to tolerate, modify toxicity, and immobilize heavy metals include 277 isolates of *Fusarium*, 6 *Aspergillus*, 73 *Trichoderma*, 1 *Chaetomium*, 20 *Talaromyces*, and 58 *Penicillium*, all cultured from plant roots.
- Investigating the optimal conditions for plants associated with fungi in surface water and soil to immobilize mixtures through adsorption and heterogeneous chemical precipitation with Ca- and Fe-bearing minerals

(A) Fungal endophytes enhance plant biomass of grasses from our work at Cheyenne River Sioux Tribe; (B) Endophyte Colonization intracellularly in plant roots.



Collaborators: Jennifer Rudgers, Jose Cerrato, and Taylor Busch

In development: Multi-group structural equation models to test hypotheses on predicted causal relationships among variables that produce the end response of As or U bio-immobilization..



Bench development → field implementation tests

Site Suitability Analysis for AUM Waste Source Removal Alternatives

UNM METALS aims to advance scientific research to inform dialogue and policy decisions about cleaning up AUMs

Goal: Identify path for consensus model to resolve differences in goals for long-term resolution of contamination.

Collect and compile data to integrate information on three criteria important to the discussions: A model for sociocultural, ecological, and hydrogeological site suitability analysis to support policy discussions about the removal, relocation, and long-term management of toxic waste from abandoned uranium mines (AUMs) and uranium mill tailings piles

Criterion 1: Hydrogeotechnical (abiotic factors)

e.g., soil chemistry, scale of permeability, baseline levels of contamination, known sources of contamination and impacted areas, surface area impacted by wind disbursement of contaminants for each point source, geophysical controls, topography (elevation, slope, temp, rainfall), surface hydrology (ponds, rivers, lakes, wetlands, discharge pathways), groundwater hydrology (cross-sectional analysis of depth of groundwater), geochemical modeling with an understanding of soil transmissivity rates and a projection of contamination

Criterion 2: Ecology (biotic factors)

e.g., soil biogeochemistry, plants, fungi, microbes; agricultural use, land cover/vegetation; animals (pastoral use; wildlife)

Criterion 3: Sociocultural (social factors)

e.g., social network map of stakeholders; statute and landownership (EPA CERCLA Superfund, DOE Legacy Management, private, Indigenous and Hispano allotment; state, federal, tribal, county, municipal); distance from point of origin to selected site; transportation (major roads, rail lines, broadband, highways); populations; cultural resource management, cultural provinces, and traditional cultural properties

Collaborators: METALS: Thomas De Pree, Chris Shuey, Daniel Beene UNM ASPIRE: Chris Lippitt NMELC: Eric Jantz, Valerie Rangel, Maslyn Locke RWPRCA/ENDAUM: Teracita Keyanna MASE: Susan Gordon. SRIC: Paul Robinson. Earle Dixon

UNM METALS Superfund Center

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- ***Blue Gap-Tachee***
- ***Cameron***

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Community and Navajo Nation Call for Removal of AUM Wastes from Navajo Nation (Diné Bikéyah) as only acceptable long-term goal

- "Calling on the Navajo Nation to lead a rigorous identification and evaluation of locations for uranium mine waste disposal *outside* of the Navajo Nation" **(Churchrock Chapter President Larry King).**
- "Rather than continue to dispose of mine waste on an *ad hoc* basis, we demand that the Federal Government devise a holistic policy of uranium mine and mill remediation that includes one or more repositories for uranium mine and mill waste" **(RWPRCA).**
- "We are more than willing to put in the work to help you understand or get a better understanding of why we say what we say, to give you an understanding of why we bring out the different examples that we share, why we say it [the mine waste] needs to go completely off of Navajo" **(Dariel Yazzie, NNEPA Superfund)**
- "the Navajo Nation remains steadfast in its position that all NECR [Northeast Church Rock] radioactive mine waste registering above USEPA's action level should be removed from the community" **(Navajo Nation President Nez and Vice President Lizer).**

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UNM METALS Superfund Center