Characterization of Chemistry and Toxicity of Ambient Particulate Matter Air Pollution Near Uranium Mine Sites on Tribal Lands of the Southwest
Native Environmental Health Equity: Addressing the Impacts of Abandoned Mines on Native Communities

- >1/2 of Native population of US lives in 13 western US states, where 161,000 abandoned hard rock mines also located

- >600,000 Native Americans live within 10 km of abandoned mines

- Greater reliance on local resources creates increased concern over potentially greater exposure and resultant impacts

Lewis, Hoover and MacKenzie, 2017, Current Environmental Health Reports

Hot Spots in the Four-Corners Region for Environmental Lung Disease: Silicosis and Interstitial Lung Disease/Sarcoidosis


Some images have been removed from this slide.
Demographics and Cardiometabolic Disease Prevalence in a Navajo Nation Cohort: The Diné-Navajo Environmental Health Study

<table>
<thead>
<tr>
<th>Variable</th>
<th>DiNEH Subset (n = 252)</th>
<th>Original DiNEH (n = 1304)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>55.3 (± 14.3)</td>
<td>51.5 (± 17.4)</td>
</tr>
<tr>
<td>Female, %</td>
<td>57.5</td>
<td>56.4</td>
</tr>
<tr>
<td><strong>Self-reported health conditions:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2 Diabetes, %</td>
<td>26.2</td>
<td>25.1</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>38.1</td>
<td>35.9</td>
</tr>
<tr>
<td>Heart Disease, %</td>
<td>6</td>
<td>5.4</td>
</tr>
<tr>
<td>Myocardial Infarction, %</td>
<td>4.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Stroke, %</td>
<td>5.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Body mass index (BMI), kg/m²</td>
<td>29.7 (26.8-33.6)</td>
<td>28.3 (25.1-32.6)*</td>
</tr>
<tr>
<td>Obesity (BMI ≥ 30), %</td>
<td>47.6</td>
<td>41.2</td>
</tr>
</tbody>
</table>

High prevalence of diabetes, hypertension, and obesity

Harmon et al., PLoS ONE, 2016

* self-report
Multivariate Regression Modeling

Covariates
Exposure metrics:
- Water intake of metals
- AUM proximity
Age, gender, BMI, HbA1c

Response variables
mRNA endothelial cell responses to serum
- VCAM-1
- ICAM-1
- CCL2

Reduced models derived by model selection using AIC

Uranium Mine Proximity (NOT Oral Intake of Arsenic or Uranium) Correlates with Inflammatory Markers in Navajo Participants

Harmon et al., JESEE, 2017
Community Research Interim Results

Closer proximity to abandoned uranium mines predicted increased serum inflammatory potential

\[ \text{Broader effect of overall burden of mining waste exposure} \]

- Other pathways → windblown?
- Other mining metals/mixtures

Could windblown contaminated dusts negatively impact public health in affected communities?

Steps in Risk Assessment:

- Hazard Identification
- Exposure Assessment
- Dose-Response Assessment
- Risk Characterization
Particulates

- “Dust” ranges in size greatly; respirable particles are generally <10 microns
- Size of particle determines how they deposit in the lungs
- Mass mean aerodynamic diameter (“MMAD”) is used to describe the size of particles
  - BASED on empirically determined particle buoyancy rather than physical shape
- PM toxicity is a function of:
  - Aerodynamic diameter
    - Deposition and retention
  - Chemical composition

Location of Claim 28 Mine Site in the Blue Gap Tachee (BGT) Chapter of the Navajo Nation

- > 500 abandoned mines
- 4 mill sites
- 1,100 exposure features
- 100s of contaminated wells (Arsenic, Uranium)
Metal Contaminants in Surface Soils

- Sediments from Claim 28 mine site contains respirable metallic mineral grains
- XANES analysis suggests many of these metallic grains are likely carnotite, a mineral composed of uranium and vanadium

![Image A. Soil](image1)

30 µm

![Image B. Carnotite](image2)

![Image C. Resuspended Material](image3)

EDS spectrum of the area in Red

Metal Contaminants in Resuspended Sediments

- Soils were resuspended in air and captured in a Next Generation Impactor to characterize respirable fractions
- Sub-micron (respirable) PM contained significant amounts of carnotite

![Image D. EDS spectrum](image4)
Carnotite Particulates Exhibit Nano-agglomerated Ultrastructure

Zychowski et al., *Toxicol Sci*, 2018

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**Initial Toxicity Assessments**: Comparing Cardiopulmonary Toxicity of Contaminated “Claim 28” PM vs Background PM

- **Dose groups** (C57BL/6, male):
  - Vehicle control aspiration
  - 100µg Claim 28 PM$_{10}$
  - 100µg Background PM$_{10}$
- **Euthanized** 24h post aspiration
- **Pulmonary inflammation**
  - Lavage Cellularity, Cytokines
- **Aortic vasomotor dysfunction**
- **Cytotoxicity assay** (*in vitro*)
**Lung Outcomes**: Lavage Inflammatory Cells and Cytokines

*Following particulate exposure in mice*

*P<0.05; **P<0.001 by one-way ANOVA with Dunnett's Post-Hoc test

Zychowski et al., *Toxicol Sci*, 2018

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**Relative Cytotoxicity Assessment**

- Treated THP-1 cells with increasing concentrations of Claim 28 and Background PM$_{10}$
- Dihydroethidium and caspase-1 levels were both elevated in THP-1 cells treated with Claim 28 PM$_{10}$

Zychowski et al., *Toxicol Sci*, 2018
Conclusions

• Proximity to mine sites may be linked to circulating inflammatory potential
• Mine site soils contain mixed metal contaminants
  – Many in respirable grains
  – Mine site–derived PM clearly more toxic to the pulmonary tract than background soil PM samples
• Both vanadium and uranium, key components of the ore carnitote, have independent and complementary pulmonary toxicity
• But how realistic are these exposures . . . ?

Where Are We in Understanding the Range of Inhaled Uranium Ore Health Impacts?

<table>
<thead>
<tr>
<th>Duration</th>
<th>Pathology</th>
<th>Exposure</th>
<th>Risk Assessment</th>
<th>Uranium Mine Site Ores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute</td>
<td>Pulmonary T(_{1/2}) 1/2/17</td>
<td>Aspiration</td>
<td>Hazard ID</td>
<td>Carnotite/Tyayuminite (Vanadium)</td>
</tr>
<tr>
<td>Subacute, single dose</td>
<td>Chronic Vascular Remodeling (Athero, HTN)</td>
<td>Dose-Response</td>
<td></td>
<td>Uraninite</td>
</tr>
<tr>
<td>Subacute/repeated</td>
<td>Neuropathy—AD, neuroinflammation</td>
<td>Exposure Assessment</td>
<td></td>
<td>Thucholite (pyrobitumen)</td>
</tr>
<tr>
<td>Chronic/repeated</td>
<td>Fetal exposure/birth outcomes</td>
<td>Inhalation</td>
<td>Risk Management</td>
<td>Coffinite (Uranium Silicates)</td>
</tr>
</tbody>
</table>
Steps in Risk Assessment:
- Hazard Identification
- Exposure Assessment
- Dose-Response Assessment
- Risk Characterization

Study Limitations, Next Steps

**Limitations:**
- Fate and transport
  - How much contaminated dust is the community actually exposed to?
  - Doses of mine dust administered to the mice are much larger than anyone living near the mine would receive.
  - Navajo residents have lived most of their lives near the site, receiving low but chronic doses over time.
  - The duration and extent of dust exposures are not well understood. On-site monitoring in 2017 will address these limitations.

**Proposed next step: Mobile Laboratory**
The Long Drive . . .

Arrival at UNM

Traffic in Blue Gap Tachee, AZ
Lung Inflammation: Pilot Study

- Exposures to concentrated PM from the Blue Gap Tachee, AZ, region caused increased levels of inflammatory cells in the lung
- We will need to compare with PM$_{2.5}$ from other regions
Overall Metals in PM from Completed Exposures, Spring 2018
(Compared with Published PM Levels from Other Regions of the Planet)

Measured Elements

Concentration (ng/m³)

Next Steps

• Move trailer to Laguna Pueblo
  – Jackpile mine is much larger and different ore type (uranium silicates) for spring 2019
  – A “neutral” or unaffected site (TBD)
  – Other??

• Assay tissues

• Complete wind dispersion modeling for SE Navajo region
The Long Drive . . .

Leaving BGT, AZ

Setting Up in Paguate, NM

Current Location in Paguate, NM

St. Anthony's mine

Jackpile mine
Interim Conclusions

• Dusts arising from uranium mine sites are more toxic than background dusts
  – Toxicity is either due to metal contaminants or morphology of PM
• However, even at close ranges, metal-contaminated dusts do not seem to make up a substantial portion of the PM$_{2.5}$ that communities experience
• Metals data from Paguate, NM, will be very informative to finalizing these conclusions

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