Multigenerational Legacy of Uranium Mining on the Navajo Nation

A community/research/tribal and federal agency partnership to determine the relationship between uranium exposure, birth outcomes, and development on the Navajo Nation

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The people of the Navajo Nation:
- 2000 Navajo families
- 110 chapters
- HEHSC, Tribal and Agency Councils, Executive Branch, NNEPA, GIB

Our funders:
- NIEHS (16 yrs)
- CDC/ATSDR (5 yrs)
- USEPA Region 9 Superfund Emergency Response (4yrs)
- NIMHHD (3 yrs)
- NNEPA (1 yr)
- NIAAA (2 yrs)

DiNEH and NBCS Research is reviewed and monitored by Navajo Nation Human Research Review Board
CEHP Research Model Since 1996

Ultimate Success of Translational Science

- Health Practitioners
- Researchers
- Community
- Policy Makers

Develop Common Language, shared concerns and questions

Iterative approach – follow the questions
Background

Why the Navajo Birth Cohort Study?

How should the research be conducted?
The PROBLEM

- More than 40 years of Cold War mining on Navajo Nation
  - > 500 abandoned, unmarked, unfenced mines left
  - > 1000 individual waste sites – all metal mixtures, all unremediated

- Communities Concerned about effects → Congress, UN
  - Concerned about Now and for future generations
  - Distrust research due to prior history of disrespect, abuse, secrecy

- Highest percentage of tribal populations localized to 13 western states
  - Highest concentration of abandoned uranium mines (>4000), as well as other hard-rock mines (>161,000) localized to same region
Health Risks to Tribal Populations

- **Little understanding of health risks in these populations**
  - Generally not accessible as a group in national datasets
  - Limited tribal-specific data, only proportional (~2%) representation (if any)

- **Differ in exposure pathways**
  - Differ in Land, Water, Resource Use Patterns, lower mobility
  - More subsistence lifestyles – greater reliance on locally grown foods → increased exposure risk

- **Many SES factors linked to health disparities**
  - Low income levels (household <$20K median)
  - High unemployment (e.g. >40% Navajo, >75% Sioux)
  - Poor infrastructure (>30% lack access to regulated water)
Water-borne toxicants:
Inorganic Metals for 427/702 unregulated wells: DiNEH Project, USACE, USEPA, USGS, CRUMP, CDC/NNEPA

Sampling bias in regions of known mining

DiNEH project sampled all wells used by participants for drinking in 20 chapters

Arsenic (~15%) and uranium (~13%) account for the majority of water sources (26%) exceeding the established MCL.

MCL = maximum contaminant level, EPA standard for safe drinking water
Reproductive and developmental concerns – tribal populations

- **50% higher prevalence for 8 tracked birth defects (Canfield et al., 2014)**
  - Doesn’t count states with highest % tribal populations – small tribal $n$
  - No assessment of environmental risk factors

- **AI/AN historically higher rates of**
  - preterm birth,
  - low (and high) birthweight,
  - miscarriage,
  - stillbirth,
  - infant death
  - hypertensive disorders,
  - preeclampsia,
  - gestational diabetes

- **Generally not represented in existing prevalence or toxicity studies**
  - no comprehensive data on birth defects, autism, developmental delays – or culturally specific developmental norms
Combined Iterative Model
Research Approach Mirrors Navajo Learning method
Basis for original DiNEH Project and current Navajo Birth Cohort Study

- Community-Researcher designed questions
- Surveys & Community data collection
- Iterative Model Development and Analysis
- Clinical Evaluations to Confirm Results, Engage Clinicians
- Laboratory Mechanistic Studies to Confirm Results
- Report-backs to Participants lead at all stages of results
- Identify next needs, remaining questions, new partners to engage
- Report-backs to NNHRRB, Navajo and Federal policy-makers

Synthesized Research Model for DiNEH Project and Navajo Birth Cohort Study
DiNEH Project Results:
Active-mining era exposures (workers and family) increased risk of kidney disease

Active-mining related exposures were estimated from self-reported survey data

A: Washed the clothes of a uranium worker (22%)
B: Worked in a uranium mine (10%)*
C: Lived in a mining camp (4%)
D: Worked in a uranium mill (2%)*
E: Worked on a uranium mine or mill reclamation or hauled uranium ore or tailings in a pickup truck (2%)

*Many workers have already died from lung cancer, cohort had more family members than workers

DiNEH Results:
Ongoing environmental legacy exposures \(\rightarrow\) increased risk for hypertension, autoimmune disease; developing one and more chronic diseases

Exposures include the following activities:
A: Used materials from abandoned uranium mine or mill (17%)
B: Herded livestock next to uranium mine, mill or waste dump (13%)
C: Drunk or contacted uranium mine waste water (13%)
D: Played on a uranium tailings pile or waste dump (13%)
E: Played outdoors near a uranium mine, mill, or waste dump (12%)
F: Sheltered livestock in an abandoned uranium mine (2%)

*Note: Median length of residence in current homes was 33 years
Also a relationship with living near mines (up to 25% do not know).

Navajo Birth Cohort Study
2010-2017 – Congressional Mandate
Cooperating Organizations

DiNEH Project Team
- UNM Community Environmental Health Program (CEHP)
- UNM Pediatrics Department, Center for Development and Disability
- Southwest Research and Information Center (SRIC)
- Consultants

Birth Cohort
Navajo mothers, fathers and babies; other community members; chapters

With Help From
- Growing in Beauty (developmental disabilities services provider)
- PL93-638 Facilities (Tséhootsooi, Tuba City)
- Other Navajo Nation Agencies (Environmental Protection Agency, WIC, Health Education, Office of Uranium Workers)
- USEPA Region 9

Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry

Navajo Area Indian Health Service (NAIHS)

Navajo Nation Department of Health
Body of work will result in data on three successive generations

- Separate exposures during active mining from those to legacy waste

- Extensive exposure characterization:
  - biomonitoring, home assessment, self-reported exposure, environmental monitoring

- Clinical and developmental assessments

- Laboratory mechanistic studies

- Understanding of Exposure Pathways:
  - Investigation of minerologic, physico/geochemical properties of waste affecting exposure & disease

- Research to understand risk, inform regulatory action, prevention strategies
Building the cohort
NBCS Birthing Hospitals in Relation to Principal Uranium Exposure Sources

Navajo Area OB/GYN Birth Statistics (2009) Self-Reported at Area and National Meetings
(Source: NAIHS clinical staff)

<table>
<thead>
<tr>
<th>Location</th>
<th>Deliveries</th>
</tr>
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<tbody>
<tr>
<td>Chinle</td>
<td>541</td>
</tr>
<tr>
<td>Tséhootsooí (638)</td>
<td>459</td>
</tr>
<tr>
<td>Gallup</td>
<td>664</td>
</tr>
<tr>
<td>Shiprock</td>
<td>763</td>
</tr>
<tr>
<td>Tuba City  (638)</td>
<td>519</td>
</tr>
<tr>
<td>Total</td>
<td>2,946</td>
</tr>
</tbody>
</table>

Note: Kayenta clinic designated by NAIHS as NBCS prenatal care facility; began enrollment October 2014, no deliveries
Outcomes Model Structure

**EXPOSURE INPUTS**

- Uranium
  - Proximity, dust, occupation, water, land use
  - Survey, GPS, NURE data, Biomonitoring, Existing water quality, in-home dust, parent biomarker analyses

- Radiation
  - Home scans
  - Biomonitoring, Existing data

- Radon
  - In-home
  - Canister monitoring

**MODIFIERS**

- Reproductive History
  - Mother and father
  - Survey & Medical Records

- Nutritional Status
  - Mother
  - WIC, FFQ, Biomonitoring

- Demographic Variables
  - Parental income, education, parental ages
  - Survey

- Alcohol, Substance Abuse
  - Surveys, Meconium, Medical Record

- Co-Exposures
  - Other metals, PAHs, Particulates, Sulfur Compounds
  - Biomonitoring, Surveys, Home Assessments

**REPRODUCTIVE OUTCOMES**

- Reproductive Difficulty
  - Miscarriage, delivery complications
  - Medical Record

- Low Birth Weight
  - Medical Record Review

- Congenital Malformation
  - Medical Record, Survey

**DEVELOPMENTAL OUTCOMES**

- Development:
  - Behavior
  - Communication, gross & fine motor skills, problem solving and personal social skills
  - ASQ-I & Mullen

- Development:
  - Physical
  - Length, weight, head circumference
  - Anthropometry

- Development:
  - Medical
  - Infections, Morbidity, Mortality
  - Medical Record Review

- Development:
  - Biomarker
  - Inflammation, Immune system
  - Laboratory Analysis
Characterizing the cohort

Biomonitoring
Home Environmental Assessments
Environmental Monitoring
Biomonitoring in the NBCS

- Multiple time points and biological media
- CDC laboratory testing for 36 different metals/metalloids of interest including arsenic, uranium, lead and mercury

<table>
<thead>
<tr>
<th></th>
<th>Blood</th>
<th>Urine</th>
<th>Meconium</th>
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</thead>
<tbody>
<tr>
<td>Mother</td>
<td>Enrollment, Delivery</td>
<td>Enrollment, Delivery</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father</td>
<td>Enrollment</td>
<td>Enrollment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baby</td>
<td>Birth (cord blood), 2-6 months of age, 12 months of age</td>
<td>Birth, 2-6 months of age, 12 months of age</td>
<td>Birth</td>
</tr>
</tbody>
</table>
Uranium distributions consistent across all service units

- Now have sufficient data to begin examining relationships between moms, dads, babies; babies over time; and relationships to exposure sources
- Cannot directly address placental transfer, U in urine at birth a concern
- Concern that babies exposures increase & at levels 3x greater than expected for adults (NHANES)

All percentile comparisons are to NHANES 2010-2011 adults – no infant comparisons found.
Levels lower than anticipated based on water and mine waste analyses
• Critical for thyroid function, normal organ & CNS development
• Highly variable analyte
• Best viewed as indicator of population sufficiency
• No prior data on Navajo
• Suggests potential for population deficit
• Preventable – supplementation, increased dairy, fish, oral supplements – Could be clinically addressed ASAP to improve birth outcomes
• But -- None of high-iodine foods in Navajo diet!
Serum zinc deficiency common in pregnancy

Sufficiency of majority of babies and dads suggests serum not best marker of functional sufficiency

VICTER: Hudson, Ho, Lewis – synergy of Zn deficiency, metal exposure, oxidative stress & DNA repair *in vitro*, *in vivo*, and in human samples
Parallel efforts

Understanding mechanisms of toxicity

Likely Exposure Pathways
Inflammation – Immunity – Metal exposure

(MacKenzie, Erdei, Ong, Rubin, Pollard)

- Our previous tribal studies showed elevated ANA with As exposure
  - (Ong et al., *Autoimmune Diseases*, 2014)
  - Specific auto-antibodies consistent with environmental autoimmunity (e.g. drug-induced Lupus)

- Elevated prevalence of ANA in older DiNEH cohort (48% by clinical screen)

- NBCS - 20% of 14-45 yo sample ANA positive (M=F) (n=40)

- Unexpected in this age range
  - NHANES data – 13.9% prevalence (Satoh et al., *Arthritis and Rheumatism*, 2012)
  - Hg study from NHANES data – 16% (Somers et al., *EHP*, 2015)
DNA Damage  
(Hudson, Cooper, Dashner, MacKenzie)

- Comet assays on samples from 36 NBCS mothers (mean age 26)
- Number of cells with damage increases with exposure
  - Urine As : Urine U interaction significant predictor of damage ($p=0.0007$)
  - 3-way interaction shows Zn reduces synergistic increase in damage linked to As:U interaction ($p = 0.006$)
  - Indications that supplements prior to pregnancy are important in reducing damage

- VERY PRELIMINARY RESULTS!!! Replicating in additional samples
- Consistent with our laboratory studies
- Suggest protective intervention possible to reduce damage
Understanding transfer at soil:water and soil:air interface

Serafina Nez and her Mother Helen. Members of Tachee Uranium Concerns Committee that requested these analyses
Tachee/Blue Gap – community concerns about living with waste – historical developmental disabilities in children, consumption of contaminated water

(Cerrato, Blake, Shuey)

METALS Monograph #1
Results presented to community, NNEPA, NNDOJ
→ USEPA Region 9
→ site now prioritized for clean-up

Abandoned Uranium Mine Waste (Northeastern Arizona):
Elevated U (6,614 mg kg\(^{-1}\))
Co-occurring metals (e.g. As, V, Fe)
U in Water (Spring): EPA MCL for U
67 – 170 µg L\(^{-1}\) > 30 µg L\(^{-1}\)

Soils: Batch extraction experiment

C.) Elemental mapping performed on MW1. Blue=Iron, Red=Uranium, Green=Vanadium, and Yellow reflects combined U and V.
Transport of waste at Air:Soil interface

BACKSCATTERED ELECTRON IMAGES and EDS SPECTRUM of CARNOTITE \([K_2(UO_2)_2V_2O_8]\) IN AUM WASTE  (Brearly)

• a, b, c and d) BSE images showing dispersed micron to submicron, free carnotite particles (arrowed) in mine waste,

• e) EDS spectrum of carnotite particles.

Air sampling to begin this spring (Campen, Gonzales, Shuey, Nez)
Sites vary, are large, and extremely close to Communities
Affect Navajo and other tribes in west

Photo montage shows spring winds resuspending dust from Old Church Rock Mine site (right) onto Navajo grazing lands (left), April 2003.
As Dust Storms increase, What IS In the Dust????

Phoenix 2012

California Valley

Phoenix Tuesday
March 2014
Tribal Lands and the Uranium Legacy

Uranium one of many minerals mined in Western U.S. primarily for weapons development.

The Uranium Legacy of the Western U.S.

- USEPA estimates:
  ~10,400 abandoned uranium “mine features” in 15 western states

- U.S. Bureau of Mines estimates:
  ~4,100 discrete uranium mines

Source: [http://www.epa.gov/rpdweb00/tenorm/uranium.html](http://www.epa.gov/rpdweb00/tenorm/uranium.html)

GAO testimony in House – 2011

- 161,000 abandoned hardrock mine sites in 12 Western states and Alaska

- 33,000 have degraded environment through contamination of surface and groundwater OR leaving arsenic-contaminated tailings

- 12 Western states and Alaska have the highest percentages of AI/AN population

Is this OK????????
Thank you

FROM THE NBCS Team!
UNM-CEHP, SRIC, NNDOH, NAIHS, CDC/ATSDR