



Casting a Broader Net—Using Art to Communicate Environmental Effects of Mining

*23 September 2021
San Juan Mining and Reclamation Conference*

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Ellen Hinck, Kate Campbell, Marie-Noele
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Outline

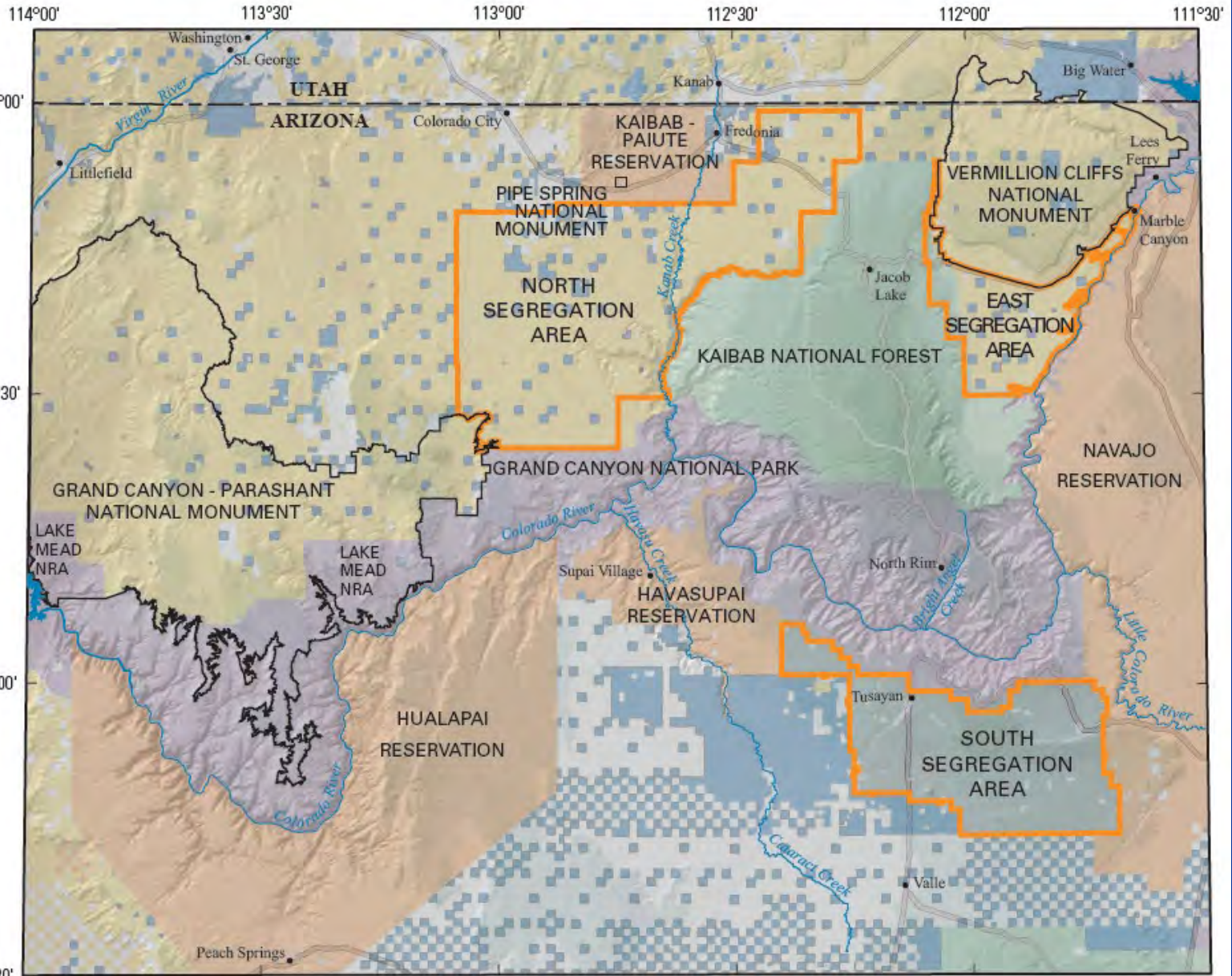
- **Background**
 - 20-year moratorium
 - USGS Science to support decision making
- **Problem:**
 - Is our science being understood?
- **Solution: Find better, more engaging ways, to communicate the science**
 - Radon graphic/comic/geonarrative
 - USGS “Fact Sheet”
 - New effort including social science and scientists

Background

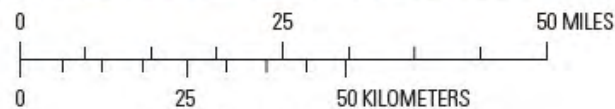
- Record of Decision (ROD) Jan. 2012– withdrawal of 1M acres
 - “The uncertainties of effects to **water quantity and quality**, also leads to **uncertainties of effects to animals and humans**. The effects of exposure of native plants and animals to increased levels of radionuclides **are unknown**.” (ROD p. 10).
 - “The EIS states that impacts are possible from uranium mining in the area, including, in particular, **impacts to water resources**. It also expresses **uncertainty with respect to hydrology and groundwater flow in the area** as well as the **potential effects of increased radionuclides to plants and animals**.” (ROD, p. 12).
- Tasked with closing these data gaps--existing permitted mines



Study Area



Data provided by U.S. Geological Survey and Bureau of Land Management.
 Map created on 11/10/09 by K.M. Brown
 Map revised on 5/24/10 by T. Arundel



SEGREGATION AREAS
 (Proposed mineral withdrawal areas)

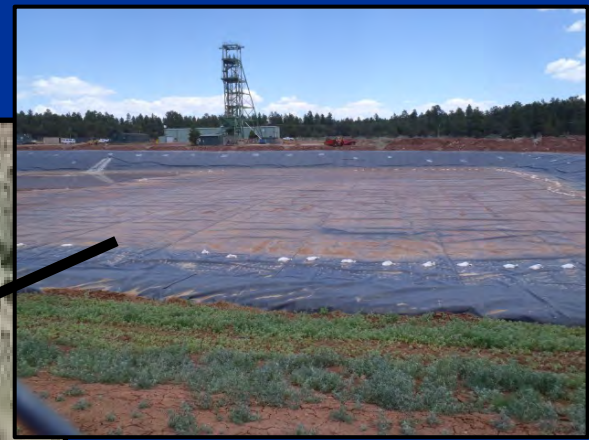


EXPLANATION	
	U.S. Bureau of Land Management
	U.S. Forest Service
	Tribal land
	National Park Service
	State land
	Private land
	Segregation area—Boundary
	National Monument—Boundary



Mine features

- Small footprint, underground mine, small deposits
- Head frame
- Detention pond
- Ore storage
- Waste rock/
overburden storage
- Peripheral berm,
internal drainage

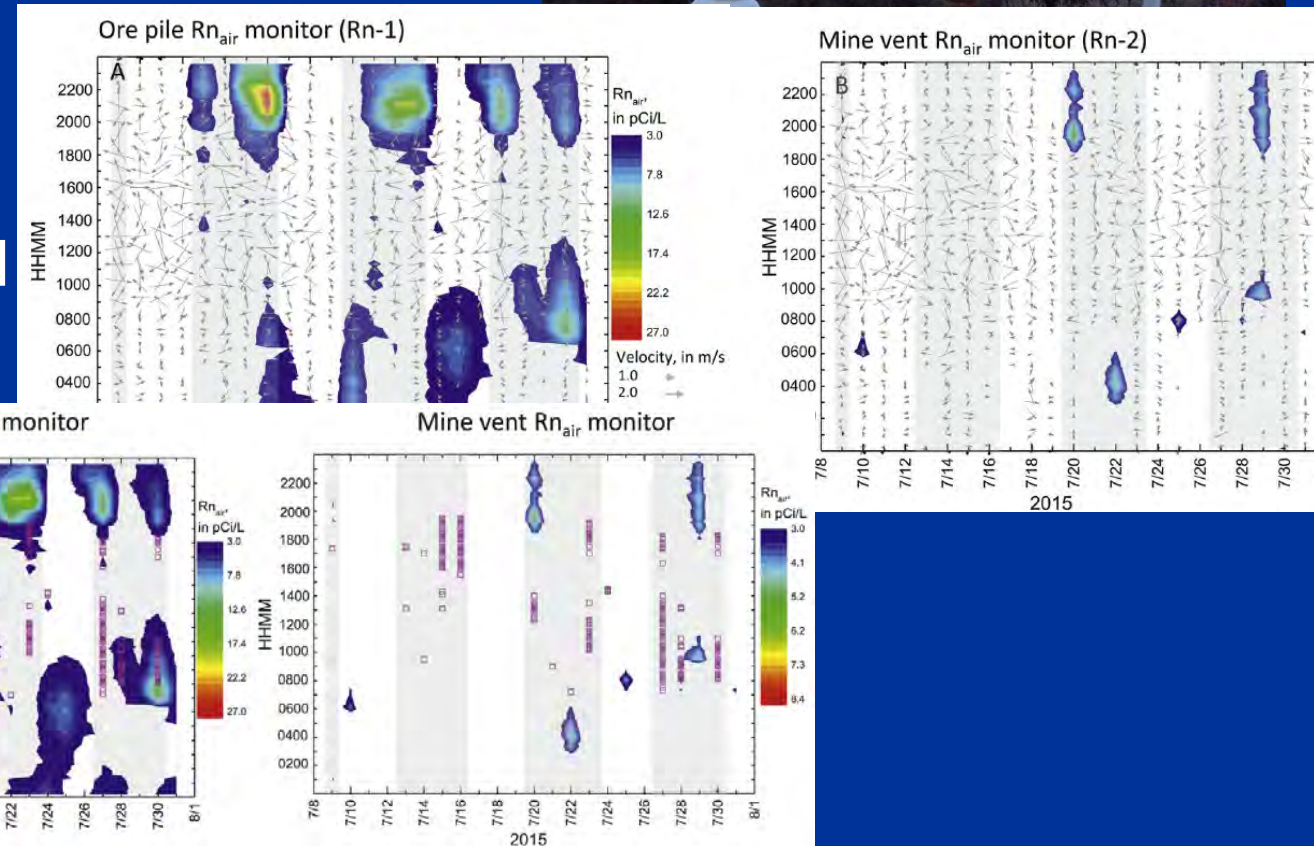
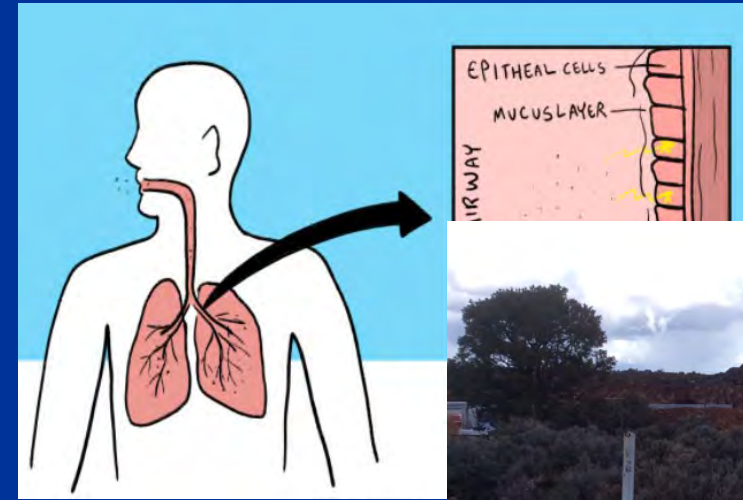


The Problem:

- *“I just sat through 3 hours of your presentations, and I did not catch most of it. Can I have your powerpoint slides? “*
- Member non-government organization: *“there are USGS studies documenting higher U concentrations in soils around the mines north of Grand Canyon...[other studies] documenting movement of material from uranium mines during flash floods in the 1980s.”* The speaker was using these statements as evidence of the effects of uranium mining on the environment.
- Mining company replies by quoting from USGS report: *“No scientific evidence of adverse environmental impacts.”*

Radon-Active Mining

- Rn health hazard to biota if inhaled
- Two radon monitors and time-lapse camera
- $Rn_{\text{ore pile}} > Rn_{\text{ventilation shaft}}$
- Rn lower on windy and rainy days.
- Physical disturbance of ore pile did not affect Rn concentrations.





Invisible: Radon Gas at the Pinenut Uranium Mine

Arizona, USA, 2015-16

Katherine Walton-Day, JoAnna R. Wendel, Jo Ellen Hinck, David L. Naftz, and Sharon L. Qi

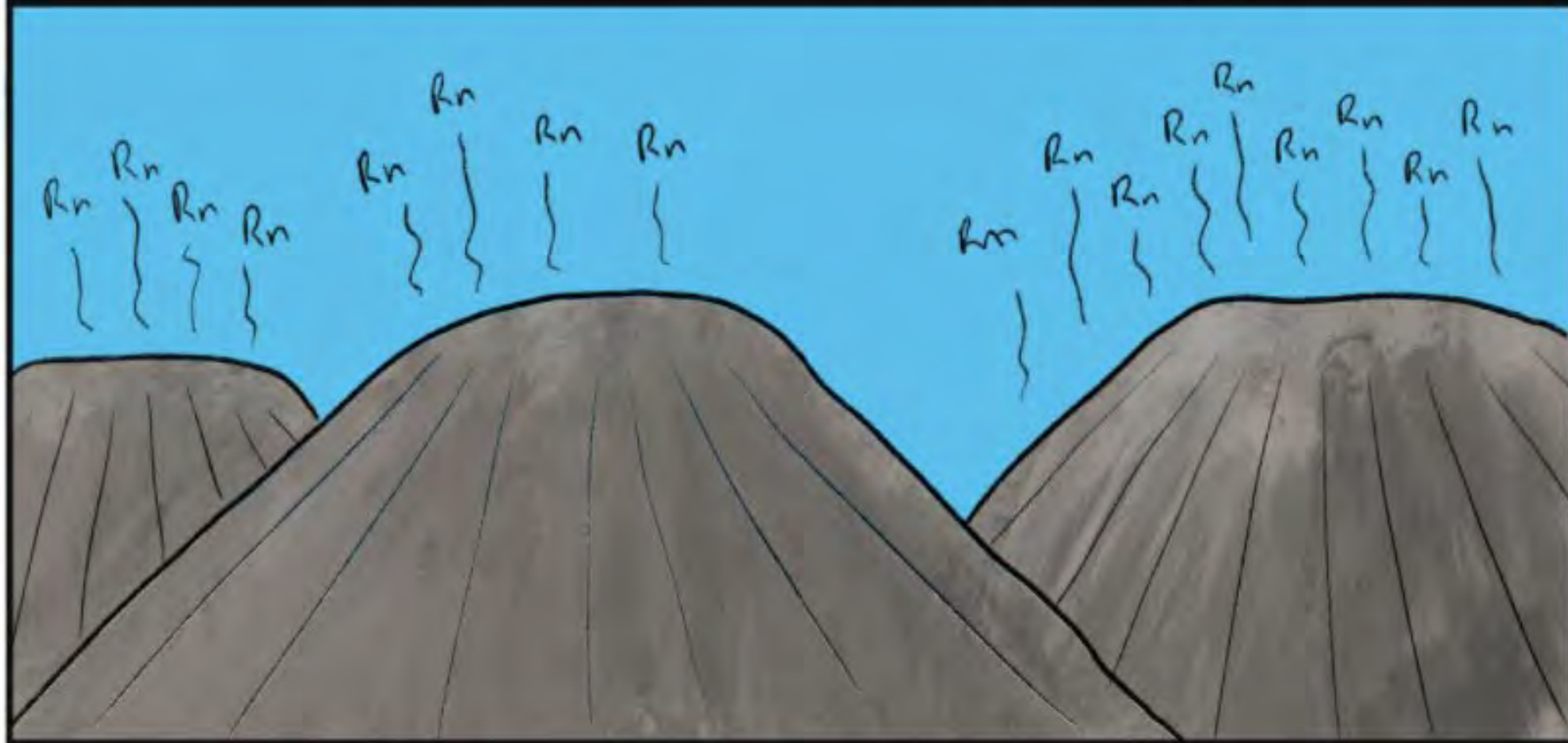
January 15, 2021

JUST NORTH OF THE GRAND CANYON LIES PINENUT MINE, A URANIUM MINE THAT PRODUCED MORE THAN 1.4 MILLION POUNDS OF URANIUM OXIDE ORE SINCE THE 1980s.

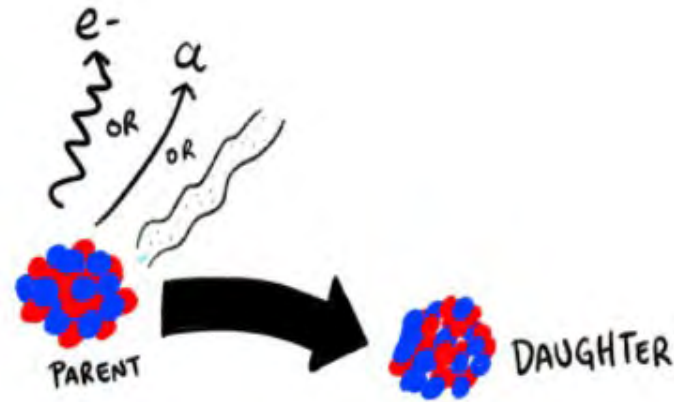
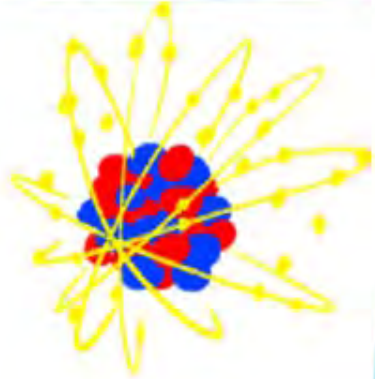


OPERATIONS AT THE MINE ENDED IN 2016, AND MOST RECLAMATION ACTIVITIES WERE COMPLETED BETWEEN 2018 AND 2019.

HOWEVER, DURING ACTIVE MINING OPERATIONS AT SIMILAR MINES, THERE'S CONCERN THAT DECAYING URANIUM IN ORE AND WASTE ROCK STORED AT THE SURFACE WILL PRODUCE ELEVATED OR POTENTIALLY HARMFUL LEVELS OF RADON (Rn) GAS.

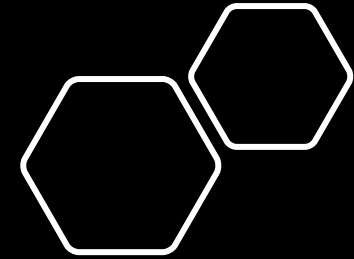
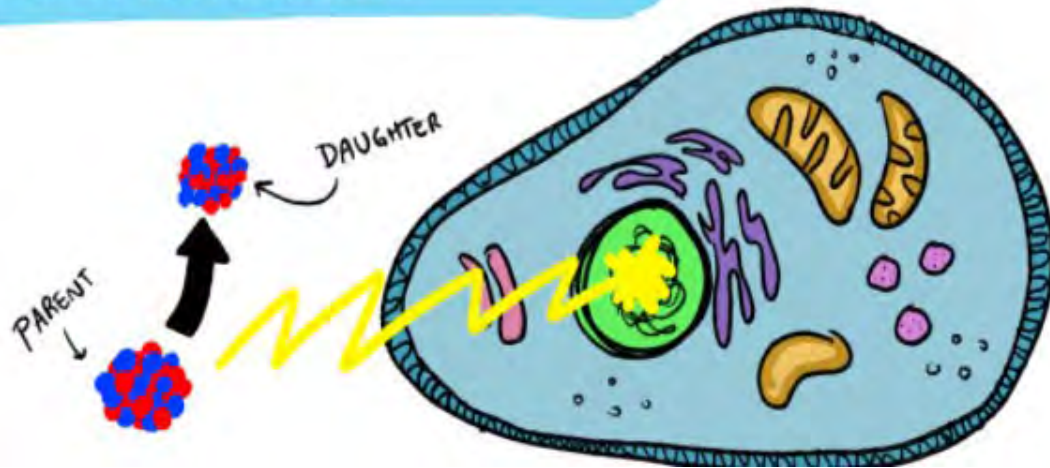


RADON IS A RADIOACTIVE PRODUCT OF URANIUM DECAY.



RADIOACTIVE ELEMENTS DECAY FROM A 'PARENT' ATOM INTO A 'DAUGHTER' ATOM EITHER BY LOSING A STREAM OF ELECTRONS (e^-) OR AN 'ALPHA' PARTICLE (α) THAT CONTAINS TWO PROTONS AND TWO NEUTRONS, OR BY EMITTING A STREAM OF HIGH-ENERGY PHOTONS.

THESE PROCESSES ARE HARMFUL TO HUMANS BECAUSE THE ENERGY OR PARTICLES GIVEN OFF CAN DAMAGE HUMAN CELLS.



BACK TO THE PINENUT MINE. IN 2015, A TEAM OF U.S. GEOLOGICAL SURVEY SCIENTISTS SET OUT TO DETERMINE HOW MUCH RADON (Rn) GAS WAS BEING RELEASED DURING MINING, BOTH FROM THE VENTILATION FROM UNDERGROUND TUNNELS AND FROM THE ORE PILE BEING STOCKPILED AT THE SURFACE DURING MINING.

THE TEAM SET UP RADON MONITORS NEXT TO THE MINE VENT AND THE ORE PILE AND THEN MONITORED THE CONCENTRATION OF RADON GAS IN THE AIR SURROUNDING THE MINE EVERY 20 MINUTES FROM MARCH 2015 TO MAY 2016.



THEY ALSO INSTALLED A TIME-LAPSE CAMERA TO DETERMINE HOW THE SIZE OF THE ORE PILE CHANGED THROUGH TIME AND WHETHER HEAVY EQUIPMENT OPERATIONS ON THE PILE INFLUENCED RADON GAS CONCENTRATIONS IN THE AIR SURROUNDING THE MINE SITE.

A WEATHER STATION AT THE SITE ALLOWED THE TEAM TO UNDERSTAND HOW RADON GAS CONCENTRATIONS IN THE AIR SURROUNDING THE MINE SITE MIGHT BE AFFECTED BY WIND SPEED, WIND DIRECTION, AIR TEMPERATURE, AND PRECIPITATION.



Rn MONITOR CAMERA

RADON GAS CONCENTRATIONS WERE GREATER THAN 3.0 PCi/L MORE OFTEN AT THE ORE PILE THAN AT THE VENT IN JULY 2015 — THIS WAS PROBABLY DUE TO THE FACT THAT THE MINE WAS STILL OPERATIONAL AND THE ORE PILE WAS LARGE.



IN FEBRUARY 2016, RADON GAS CONCENTRATIONS MEASURED LESS THAN 3.0 PCi/L, PROBABLY BECAUSE MINING OPERATIONS HAD STOPPED AND MOST OF THE ORE HAD BEEN TRANSPORTED TO A PROCESSING SITE, REDUCING THE MASS OF THE ORE PILE.



AS OF 2021, THE PINENUT MINE HAS BEEN MOSTLY RECLAIMED AND ALL OF THE ORE PILES ARE GONE. THE TEAM HOPES THAT THE DATA COLLECTED ABOUT RADON GAS AT THE PINENUT MINE WILL HELP STATE AND LOCAL HEALTH OFFICIALS BETTER QUANTIFY RISK FROM RADON GAS TO PEOPLE IN PUBLICLY ACCESSIBLE AREAS NEAR BOTH ACTIVE AND RECLAIMED URANIUM MINES.

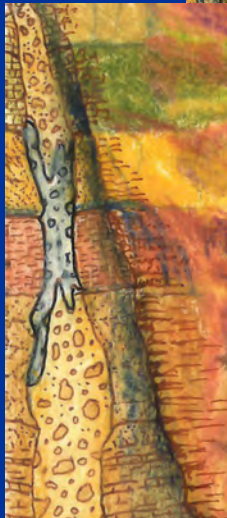


Joanna Wendel

USGS Fact 4p. Fact Sheet

- Summarizes ~ 20 scientific studies
- Art “centerfold” depicts important aspects of the study area
 - Surrounded by one-two sentence science summaries
- Will be available in print and online
- Using the engaging visuals of this artist’s work to draw in the audience





What have we learned about how mining affect resources - land, water, and biological - that humans use?

Uranium is important, but it's not only about uranium.

Mining increases uranium and chemical levels in soil. Reclamation procedures helps decrease soil levels, but they do not return back to pre-mining levels. 16, 17

Ore contains many elements besides uranium: arsenic, copper, silver, lead, zinc, cobalt, molybdenum, and nickel minerals. 19

Wind can move mining-related chemicals off-site of the mine. 5

Ore piles produce greater radon levels than the mine vent during active mining. Wind and rain reduce radon accumulation in air around the mine. Radon risk thresholds for outdoors are not available. 18

Studies at mine sites have shown uranium is not the driver of risk for animals³

We used traditional and new survey tools to understand how mining activities can affect local food webs. Chemicals can enter animals by ingestion, inhalation, absorption, and dietary transfer. 4-9

Risks from mining related-chemicals were low for terrestrial animals. Animals that eat invertebrates may have risk from arsenic, cadmium, copper, and zinc. Risk to aquatic animals is unknown. 3



Mines are not always the source of uranium in water¹

Natural sources of uranium are in groundwater and spring water.

Uranium is associated with calcium and carbonates in some Grand Canyon spring water. These forms of uranium are not available to animals. 13

Uranium and other chemical levels in water in the Colorado River in GCNP are low, but sometimes higher in tributaries where mining has or will occur. On average, these tributaries contribute very small amounts of uranium and other chemicals to the Colorado River.1,20

Deep groundwater feeding some south rim springs contains some relatively young water. Thus, groundwater is potentially more vulnerable to contamination from activities at the surface than previously thought. Solder and Beisner 2020 a,b.

Aquatic insects are unlikely to transport uranium from aquatic to terrestrial environments¹⁴

Aquatic invertebrates, including wild populations of mayfly larvae, take up little uranium because uranium in the water they live in is in forms that are not biologically available. Ingestion and retention of uranium associated with food are also modest 13-14. In mayflies, uranium accumulated in tissues is rapidly eliminated, which further reduces the quantity of uranium in their bodies.

Studies at mine sites have shown adverse effects to plants and terrestrial animals from U mining-related chemicals are unlikely even with long-term (30 year) exposure¹¹

Radiation levels in plants and animals were low. Radiation enters rodents through soil interactions (burrowing, incidental ingestion, bathing, etc.) or their diet. Radium-226 was below protective levels. It is of most concern for rodent health. 5,10,11

Plants and animals take up mining-related radionuclides, uranium, other elements but direct effects were not found. Arsenic and selenium may be harmful to aquatic animals like tadpoles. 5,11,12

New Effort

- Working in collaboration with Eric Welch and Lesley Michalegko (Arizona State University)
- Use social science to match message format to intended audiences and examine challenges of communicating science about this topic
- Develop engagement strategy for interested parties
- Review and synthesize existing products
- Use findings to develop at least one new communication product.

Summary

- Working within our institutional guidelines (peer-reviewed publications) to develop products that communicate our results in a different way
- Important to reach a broad audience and accurately communicate our results.
- The greater the understanding of the results, the greater the amount of informed discussion about underlying issues.

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Elemental and radionuclide exposures and uptakes by small rodents, invertebrates, and vegetation at active and post-production uranium mines in the Grand Canyon watershed

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^b U.S. Geological Survey, National Wildlife Health Center, 2080 Steinhilber Road, Madison, WI, 53711, USA

HIGHLIGHTS

- First report of elements, radionuclides, in biota at active, post-production uranium mines near Grand Canyon.
- Biota take up mining related radionuclides, uranium, other elements.
- Some element concentrations remain elevated after cessation of active mining.
- Insect larvae, spiders, mydgalophrons, soil, and soil may vary in mining signatures in biota.
- Prevalence and severity of lesions in livers and kidneys not definitively linked to mining.

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 Northern Arizona

Abstract:
 The effects of breccia pipe uranium mining in the Grand Canyon watershed (Arizona) on ecological and radionuclide exposure are largely unknown. We characterized the exposure of biota to uranium and co-occurring toxic elements during active production and at a site where ore production had recently ceased. Our results indicate that biota have taken up uranium and other elements (i.e., arsenic, cadmium, copper, molybdenum, nickel) from exposure to soil and surface contamination, like blowing dust. Results indicate the potential for prolonged exposure to elements and radionuclides upon completion of active ore production. Soil scanning 226 in deer mice was up to 1 times greater than in common shrew and meadow lark in these same samples; this may indicate a potential for, but does not necessarily imply, radium 226 toxicity. Soil screening benchmarks for uranium and molybdenum and other toxic elements for arsenic, copper, selenium, uranium (i.e., growth effects) were exceeded in vegetation, invertebrates, and rodents (average spp.). However, lesions (acute, chronic, hepatic, hemolytic) were observed. The prevalence and severity of microscopic lesions in rodent tissues (as direct evidence of exposure) and invertebrates could not be definitively linked to mining; the data indicate that land mammals might consider factors like species, seasonal changes in environmental concentrations, and bioavailability when determining mine permitting and remediation in the Grand Canyon watershed. Ultimately, our results will be useful for site-specific ecological risk analysis and can support future decisions regarding the mineral extraction withdrawal in the Grand Canyon watershed and elsewhere.

Natural and anthropogenic processes affecting radon releases during mining and early stage reclamation activities, Pinenut uranium mine, Arizona, USA

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ABSTRACT

Radon (²²²Rn) was monitored in open air in publicly accessible areas surrounding the Pinenut Uranium (U) mine during mining and reclamation activities in 2019–16 to address concerns about mining related radon releases to areas surrounding Grand Canyon National Park (GCNP) in Arizona, USA. During July 2019, ²²²Rn concentrations associated with the ore storage pile monitoring site were larger than those at the mine vent monitoring site and likely resulted from the relatively large amount of ore stored on site during this period. Higher wind velocities at the mine vent likely reduced the ²²²Rn concentrations however, wind velocity did not appear to be an important factor in controlling ²²²Rn concentrations at the mine vent monitoring site. Physical disturbances of the ore pile by heavy equipment did not coincide with elevated ²²²Rn concentrations at the ore storage pile or mine vent monitoring site. The relative size of the ore storage pile showed a positive trend with the daily mean ²²²Rn concentration measured at the ore pile monitoring site. Principal component analysis (PCA) was applied to the ore pile and mine vent monitoring data sets for simultaneous comparison of all measured variables during 120 days of the study period. A significant positive coefficient for ²²²Rn was associated with a significant negative coefficient for wind speed for principal component 020. In fact, significant positive ²²²Rn was associated with wind direction, wind velocity, and relative humidity, suggesting that ²²²Rn variations at the mine vent monitoring site may be affected by ²²²Rn sourced from the ore pile. The ore pile is located about 200 m south of the mine vent fan monitor with the prevalent wind direction coming from the south. All data generated during the field study and laboratory verification runs were published by Naitz et al. (2018) and are available online at <https://doi.org/10.5666/JER.1929441>.

1. Introduction

Radon (²²²Rn) is a naturally occurring radioactive noble gas (Cordell, 1987). Uranium (U) mining activities can be associated with elevated Rn concentrations measured in samples of indoor and outdoor air (Czupka ^{et al.}, 2009; Szymanski ^{et al.}, 2009; Penland ^{et al.}, 2005). Several factors associated with mining activities include ore storage areas, ore crushing and grinding, ore processing, mill尾矿 production, and tailings impoundments (Charley ^{et al.}, 1990). The average ²²²Rn is produced by the alpha decay of radium (²²⁶Ra) in the U decay series and has a half-life of 3.82 days (Saldaña ^{et al.}, 2011). Inhalation of the above-ground daughters of Rn are known to cause lung cancer (Ciomari ^{et al.}, 2003). Recent epidemiological studies combining seven residential case-control studies in North America provided direct evidence of an association of residential radon and lung cancer risk, consistent with previous studies focusing on underground miners (Drewell ^{et al.}, 2009; Schaebe-Berigan ^{et al.}, 2009). As an inert gas, Rn mobility in interconnected pore spaces can be affected by grain distribution, grain size, moisture content, and temperature (Saldaña ^{et al.}, 2011). Previous studies have monitored the concentration of ²²²Rn in active, abandoned, and reclaimed U mines. The World Health Organization recommends a reference level for ²²²Rn of 2.7 Becquerels per liter (Bq/L) for indoor air compared with the average baseline ²²²Rn concentration in outdoor air of 0.4 pCi/L (World Health Organization, 2009). High ²²²Rn concentrations (mean = 18 pCi/L) have been measured in dwellings near the surface projection of a tunnel associated with a closed underground U mine in Hungary (Szmalci ^{et al.}, 2008). An AlphaSABAR instrument was used for continuous monitoring of ²²²Rn concentrations around waste rock piles associated with legacy U mines in Japan (Owata ^{et al.}, 2002), where elevated ²²²Rn was measured at selected monitoring locations. The calculated effective dose was less

1. Introduction
 Solution-collapse breccia pipes in the Grand Canyon region host some of the highest-grade uranium (U)-bearing ore in the United States. Mineralized breccia pipes are located on or immediately adjacent to Federal, State, and Tribal Lands both north and south of the Grand Canyon National Park and the Colorado River. The U ores are intergrown with co-occurring sulfide and oxide minerals, often resulting in enriched concentrations of copper (Cu), lead (Pb), molybdenum (Mo), arsenic (As), and other elements (Alpiner, 2010).

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Abstract
 Better characterization of the geochemical evolution of groundwater south of Grand Canyon, Arizona (USA), is needed to understand natural conditions and assess potential effects from breccia-pipe uranium mining in the region. Geochemical signatures of groundwater at 28 sampling locations were evaluated; baseline concentrations for select trace elements (As, B, Ba, Cr, Li, Mo, Rb, Se, Sr, Tl, U, V) were established, and geochemical and mineralogical characteristics were identified. Concentrations at some groundwater sites exceeded the USEPA drinking water standard for As of 10 µg/L (Red Canyon, Miners, JT, Havasu, and Warm Springs) and U of 30 µg/L (Salt Creek Springs). Four springs from the study area (Blau, Havasu, Fern, and Warm Springs) had unique chemistry, which may indicate a deep flow or potential contribution of fluids from lower in the crust. Other springs in the study area were distinguished by major anion water type: sulfate, bicarbonate, and a mixture of the two. Water type distinctions were somewhat spatially segregated, with sulfate type present on the western side of the study area, bicarbonate type on the eastern side, and a mixture of the two interspersed between the endmember sites. Sulfate-type water from this study area had low strontium isotopic ratio (⁸⁷Sr/⁸⁶Sr) values. The location of spring discharge within single drainages of the Grand Canyon may influence chemistry, as groundwater discharging from bedrock was altered after flowing through alluvial material. Geochemical analysis of groundwater in Grand Canyon indicates the importance of continued monitoring and better understanding of short-term chemical fluctuations.

Keywords Uranium · Strontium · Geochemistry · Springs · USA

Introduction

On the arid South Rim of the Grand Canyon in Arizona (USA), water is a limited resource. Local populations and ecosystems are dependent on groundwater. The geochemical evolution of the groundwater as it moves through the subsurface, affecting the suitability for consumption, is not well understood. Increased development, uranium mining, and climate change may introduce changes to the groundwater

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system and focused studies are needed to understand the timing and effects from these changes. In 2012, then US Secretary of the Interior, Ken Salazar, initiated a removal of over 1 million acres in three segregation areas of federal land (north, east, and south) in the Grand Canyon region from new uranium mining activities for the following 20 years, subject to valid existing rights (US Department of the Interior, 2012). A key factor in the decision for the withdrawal was the limited amount of scientific data and resulting uncertainties on the

Terrestrial ecological risk analysis via dietary exposure at uranium mine sites in the Grand Canyon watershed (Arizona, USA)

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^b Ecological Risk, Inc. 13010 Major Ln., Buxton, Missouri, CA, 65614, USA

HIGHLIGHTS

- First terrestrial ecological risk analysis at uranium mines near Grand Canyon.
- Uranium was not the driver of ecological risk.
- Arsenic, cadmium, copper, and zinc are of concern for biota consuming invertebrates.
- No observed adverse effect levels were not exceeded for herbivores or carnivores.
- Relative risks were generally low for all biological receptor models.

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The US Department of the Interior, recently included uranium (U) on a list of mineral commodities that are considered critical to economic and national security. The uses of U for commercial and residential energy production, defense applications, medical device technologies, and energy generation for space vehicles and satellites are known, but the environmental impacts of uranium extraction are not always well quantified. We conducted a screening level ecological risk analysis based on exposure to mining related elements via diet and incidental soil ingestion for terrestrial biota to provide context to chemical characterization and exposure at breccia pipe U mines in northern Arizona. Relative risk calculations at hazard quotients (HQs), were generally low for all biological receptor models. Our models screened for U to invertebrates and invertebrates (IDOs) but not herbivores and carnivores. Uranium was not the driver of ecological risk; arsenic, cadmium, copper, and zinc were of concern for biota consuming ground dwelling invertebrates. Invertebrate species composition should be considered when applying the results of dietary intake to future sampling at the breccia pipe mine sites. Bioassay concentration thresholds (BCTs) were also calculated to understand food concentrations that may lead to ecological risk. The BCTs indicated that critical concentrations were not approached in our model area. Further work is needed to understand the very low HQs for carnivores. The BCTs may be used by natural resource and land managers as well as uranium operators to screen or monitor for potential risk to terrestrial receptors at mine sites as developed and remediated in the future.

1. Introduction

The United States was a leading producer of uranium (U) from the mid-to late 20th century, with U primarily used for nuclear power production (EPA, 2006). When U prices declined in the late 1970s, the large deep deposits of U first used in the nuclear

States could not compete with higher-grade deposits in Australia and Canada. Uranium production in the United States consequently dropped significantly (EISA, 2010). However, energy independence and energy dominance of domestic mineral resources has been emphasized within the United States in recent years. In 2018, the US Department of the Interior published a list of mineral commodities that are considered critical to economic and national security (Federal Register, 2018). Uranium was included on the list of minerals being identified as critical for commercial and res-

Uranium Bioaccumulation Dynamics in the Mayfly *Neoclaoen triangulifer* and Application to Site-Specific Prediction

Brianna L. Henry, Marie-Noëlle Croteau^a, David M. Walters, Janet L. Miller, Daniel J. Cain, and Christopher C. Fuller

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ABSTRACT: Little is known about the underlying mechanisms governing the bioaccumulation of uranium (U) in aquatic insects. We experimentally parameterized conditional rate constants for aqueous U uptake, dietary U uptake, and U elimination from the aquatic mayfly *Neoclaoen triangulifer*. Results showed that the species accumulates U from both the surrounding water and diet, with waterborne uptake prevailing. Elevated dietary U concentrations decreased feeding rates, presumably by altering food palatability or impairing the mayfly's digestive processes, as both nearly 90% of the accumulated U was eliminated within 24 h after the waterborne exposure ceased, reflecting the desorption of weakly bound U from the insect's gut contents. To examine whether the experimentally derived rate constants for *N. triangulifer* could be generalized to biotid mayflies, mayfly U concentrations were predicted using the water chemistry and U measured in periphyton from springs in Grand Canyon (United States) and were compared to U concentrations in spring-collected mayflies. Predicted and observed mayfly U concentrations were in good agreement. Under the modeled site-specific conditions, waterborne U uptake accounted for 52–93% of the bioaccumulated U. Accumulation was limited to these wild populations due to a combination of factors including low concentrations of bioavailable dissolved U species, slow U uptake rates from food, and fast U elimination.

INTRODUCTION
 Natural contamination of aquatic ecosystems is a global environmental issue that is often related to mineral extraction.¹ It is linked to a variety of negative impacts on aquatic ecosystems including detrimental effects on aquatic insect communities that form the prey base for many aquatic and terrestrial organisms and play a vital role in many ecosystem functions such as organic matter processing. Insect larvae accumulate metals from both exposure and dietary exposure routes,² triggering adverse effects ranging from feeding and growth inhibition to death.³ Elevated metal exposures, such as those occurring in water bodies in mined watersheds, can eliminate sensitive species, thus altering the structure of insect communities (and the trophic linkages of aquatic food webs).⁴ Furthermore, the consumption of metal-contaminated aquatic insects can impart physiological functions and survival rates to predators (e.g., fish),⁵ implying that metal trophic transfer can decrease fitness and population size of aquatic invertebrates. Given that metal bioaccumulation is also a precursor of toxicity and a key step to trophic transfer, understanding the underlying processes controlling metal uptake and loss can help inform risk assessment.

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REPORT
 Geochemical characterization of groundwater evolution south of Grand Canyon, Arizona (USA)
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Abstract
 Better characterization of the geochemical evolution of groundwater south of Grand Canyon, Arizona (USA), is needed to understand natural conditions and assess potential effects from breccia-pipe uranium mining in the region. Geochemical signatures of groundwater at 28 sampling locations were evaluated; baseline concentrations for select trace elements (As, B, Ba, Cr, Li, Mo, Rb, Se, Sr, Tl, U, V) were established, and geochemical and mineralogical characteristics were identified. Concentrations at some groundwater sites exceeded the USEPA drinking water standard for As of 10 µg/L (Red Canyon, Miners, JT, Havasu, and Warm Springs) and U of 30 µg/L (Salt Creek Springs). Four springs from the study area (Blau, Havasu, Fern, and Warm Springs) had unique chemistry, which may indicate a deep flow or potential contribution of fluids from lower in the crust. Other springs in the study area were distinguished by major anion water type: sulfate, bicarbonate, and a mixture of the two. Water type distinctions were somewhat spatially segregated, with sulfate type present on the western side of the study area, bicarbonate type on the eastern side, and a mixture of the two interspersed between the endmember sites. Sulfate-type water from this study area had low strontium isotopic ratio (⁸⁷Sr/⁸⁶Sr) values. The location of spring discharge within single drainages of the Grand Canyon may influence chemistry, as groundwater discharging from bedrock was altered after flowing through alluvial material. Geochemical analysis of groundwater in Grand Canyon indicates the importance of continued monitoring and better understanding of short-term chemical fluctuations.

Keywords Uranium · Strontium · Geochemistry · Springs · USA

Introduction
 On the arid South Rim of the Grand Canyon in Arizona (USA), water is a limited resource. Local populations and ecosystems are dependent on groundwater. The geochemical evolution of the groundwater as it moves through the subsurface, affecting the suitability for consumption, is not well understood. Increased development, uranium mining, and climate change may introduce changes to the groundwater

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