

Uranium Exposure in American Indian Communities: Health, Policy, and the Way Forward

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BACKGROUND: Uranium contamination of drinking-water sources on American Indian (AI) reservations in the United States is a largely ignored and underfunded public health crisis. With an estimated 40% of the headwaters in the western U.S. watershed, home to many AI reservation communities, being contaminated with untreated mine waste, the potential health effects have largely been unexplored. With AI populations already facing continued and progressive economic and social marginalization, higher prevalence of chronic disease, and systemic discrimination, associations between various toxicant exposures, including uranium, and various chronic conditions, need further examination.

OBJECTIVES: Uranium's health effects, in addition to considerations for uranium drinking-water testing, reporting, and mitigation in reference to AI communities through the lens of water quality, is reviewed.

DISCUSSION: A series of environmental health policy recommendations are described with the intent to proactively improve responsiveness to the water quality crisis in AI reservation communities in the United States specific to uranium. There is a serious and immediate need for better coordination of uranium-related drinking-water testing and reporting on reservations in the United States that will better support and guide best practices for uranium mitigation efforts. <https://doi.org/10.1289/EHP7537>

Introduction

Uranium mining in the United States started in 1913, with the majority of mining occurring between 1947 and 1970 due to U.S. defense-related purposes and with production needs changing toward more commercial needs after 1970 (U.S. Department of Energy 2014). Uranium mining activities and the locations of these activities were often not recorded at the state level because of national security concerns and frequently lacked oversight or regulation during this time (Edward 2015). The legacy of these mines is the continued levels of uranium present in the environment, including in many surface and groundwater sources.

In the last 10 y, there has been increased research regarding the health-related effects of uranium on local American Indian (AI) tribal members. An estimated 286,346 AI people in the United States live <10 km from a uranium/vanadium mine, with an undercount likely of between 5% and 20% due to U.S. Census data collection issues on reservations (Lewis et al. 2017). It has also been estimated by the U.S. Environmental Protection Agency (EPA) that 40% of the stream reaches in the headwaters of the western U.S. watershed, home to many AI communities (e.g., California, New Mexico), have been contaminated with untreated mine waste (U.S. EPA 2000) owing to historical exemptions from the Clean Water Act (CWA) (Lewis et al. 2017). One example of this historical exemption is the 1872 Mining Law, which essentially allows discharge of untreated mine waste into surface water (U.S. EPA 2000).

High levels of uranium in drinking-water aquifers have been identified in the High Plains and Central Valley areas of the country (Nolan and Weber 2015), in addition to various watersheds, including areas in the southwest (Lewis et al. 2017). The Navajo Nation, for example, is located in the states of Arizona, New Mexico, and Utah and has more than 500 abandoned uranium mines directly on tribal lands (Harmon et al. 2018). In a publication from 2011, the Pine Ridge Indian Reservation, located in South Dakota, had surface water samples and groundwater samples that tested at up to 100% (i.e., 60 ppb) and 33% (i.e., 40 ppb), respectively, over the U.S. EPA maximum contamination level (MCL) of 30 ppb (Botzum et al. 2011). Although naturally occurring uranium in drinking-water aquifers is known to be present within certain regions of the United States, such as the Black Hills in South Dakota, the scale of long-term aquifer contamination from *in situ* leaching from previous uranium mining remains largely unknown (Fettus and McKinzie 2012).

Uranium mining's impact on the other parts of the natural environment that are used by AI communities (e.g., soil, plants, harvested animals) is less clear, although some preliminary evidence is being collected in this area (Rock et al. 2019). The Jackpile Mine, which is located on the Pueblo of Laguna in New Mexico, was once the world's largest open-pit uranium mine, and yet, the Agency for Toxic Substances and Disease Registry (ATSDR) currently states that it does not have enough information to conclude whether eating fish, animals, or plants collected or processed downstream from the site could harm human health (ATSDR 2018). With potential uranium exposure occurring mainly through ingesting uranium in drinking water and from food either grown or harvested from areas with contaminated soil (Shelley et al. 2014), exploration of the continued health impacts of uranium on AI communities is warranted.

The Indian Health Service (IHS) Office of Environmental Health and Engineering itself provides technical and financial assistance to tribes to promote a healthy environment through safe water, wastewater, and solid waste systems and related support facilities (IHS 2021); however, resources across IHS are limited and inadequate to meet AI tribal needs (Warne and Frizzell 2014). A large discrepancy exists in the percentage of small water systems that meet the standards on tribal lands vs. in the overall U.S. population, and many of these violations are considered

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serious health violations by the U.S. EPA (Bienkowski 2016). In addition, various entities have overlapping or independent environmental responsibility and jurisdiction throughout Indian country (e.g., the IHS, tribal governments, U.S. EPA), which makes cohesive preventive and mitigation work more difficult to coordinate and operationalize. For example, U.S. EPA Region 8 covers four separate IHS operating regions and six states.

The U.S. EPA is responsible for both setting water quality standards (WQS) and the enforcement of those standards through the Safe Drinking Water Act (SDWA) (U.S. EPA 2020d). State and tribal governments may also set their own WQS and have enforcement of their WQS within their respective jurisdictions. Neither states nor tribes, however, can set any WQS above that of the federal level but may set stricter standards (i.e., lower thresholds), should they choose. Having multiple tribal and state WQS in the same watershed can therefore result in jurisdictional confusion and conflicts between the tribes and states, and can leave many wells and other water access points untested.

On tribal lands, drinking water is regulated by the SDWA (42 U.S.C. Section 300f), whereas water accessed from wells on tribal lands, which are most often installed by federal agencies, including the Bureau of Land Management (BLM) or IHS, are not regulated. These wells installed by the BLM and IHS are mainly meant for livestock and not for human consumption and are therefore not monitored or regulated. However, due to the deteriorating or lack of drinking-water infrastructure on tribal lands, including the Navajo Nation, where ~30% or more of their households are without direct access to public water systems (U.S. Department of the Interior: Bureau of Reclamation 2018), the closest and only water source is, therefore, unmonitored and unregulated federal wells (Center for American Indian Health 2020; James 2020). The protection, testing, and mitigation of groundwater therefore becomes very relevant to communities not connected to public drinking-water systems.

Furthering the complexity of water quality management on tribal lands is the lack of adequate funding available for tribes in dealing with testing, reporting, and mitigation efforts (U.S. Commission on Civil Rights 2003; Morales 2019). In the 1987 CWA Amendments, Congress authorized the U.S. EPA to treat eligible tribes in a “manner similar to states” (TAS) for the purpose of administering CWA regulatory programs and receiving federal grants (Diver 2018). The task of applying and successfully attaining TAS status has proven to be quite arduous for the majority of tribes. Of the 574 tribes, “69 tribes have been found eligible to administer a WQS program and the U.S. EPA has approved WQS for 45 of these tribes. The U.S. EPA has promulgated federal WQS for 1 tribe (Colville Reservation)” according to the U.S. EPA (2020a).

The difference between a tribe attaining WQS TAS status or not is an important issue. This is because tribes that have attained TAS status have the ability to protect their water from outside sources of contamination, whereas tribes that do not have TAS status do not (Diver 2018). For example, the Isleta Pueblo of New Mexico could enforce up stream nonreservation water use by setting stricter WQS, which would, therefore, require the respective upstream water users to improve their WQS to protect the tribe downstream. Without WQS TAS status, the tribe would have a much more difficult time enforcing these upstream WQS to protect their own waters. It is also important to note that, in 2016, the U.S. EPA issued the CWA Final Rule 303(d), which allowed tribes to partner with the U.S. EPA to influence off-reservation water users, significantly increasing tribal authority over reservation waters regardless of land ownership status (Diver 2018). Lastly, tribes with CWA TAS status also have a higher chance of being funded to protect their watersheds and

therefore can be bolstered with U.S. EPA funding through grants compared with non-TAS tribes (Diver 2018).

General federal funding programs such as the Water Infrastructure Improvements for the Nation Act (WIIN Act), Section 2014, authorized a new tribal grant program to assist tribal public water systems in underserved, small, and disadvantaged communities to meet and comply with the requirements of the SDWA (U.S. EPA 2020f). Of the \$42,854,000 allotted federally for this program, \$875,000 was available to all 574 tribes in the fiscal years 2018 and 2019 (U.S. EPA 2020f). Furthermore, in our experience, a financial match requirement [45% of the total costs of the project or activity (U.S. EPA 2020c)] for tribes in this grant hinders many of the tribes from being able to apply for the funds (i.e., due to poverty, they often do not have the funds available to meet the financial match percent required to even apply). Many tribes also do not have the personnel capacity to define the “small, disadvantaged, or underserved community” criterion required in the grant application (U.S. EPA 2020c). Because sustainable and adequate drinking-water infrastructure in AI communities is a strong precursor for the ability to ensure clean drinking water for tribal members, these funding deficits act as large barriers for safe water quality management within tribal territories.

Some AI communities have been actively working with non-profit organizations to help manage their drinking-water crisis due to the current funding void (Roller et al. 2019). The Navajo Nation, for example, has been working directly with the organization DigDeep to help improve their precarious water situation (DigDeep Right to Water Project 2020). We have personally seen several organizations partner with AI communities and feel that they should be commended for their supportive work in helping to ensure the safe access to drinking water in reservation areas given the protracted funding barriers.

We feel, that despite the many continued challenges on tribal lands regarding the sustainable access to clean drinking water, effective research, planning, implementation, and engagement with best practices are possible, with better clarity on the current state of affairs and needs within AI communities. In our experience, uranium contamination, specifically of drinking-water sources on AI reservations in the United States, has been a largely ignored and underfunded public health crisis. Furthermore, discussions around environmental racism have not often been adequately amplified in the context of AI communities and uranium exposure. We therefore seek in the remainder of this commentary to provide a general overview of uranium’s human health effects both within and outside AI communities while additionally providing considerations for uranium drinking-water testing, reporting, and mitigation within AI communities. Although this is not meant to serve either as a comprehensive etiological or epidemiological review of uranium sources, exposure, or mitigation efforts in AI communities, we have, however, identified a series of preliminary environmental health policy recommendations with the intent to proactively improve responsiveness to the water-quality crisis in AI reservation communities in the United States specific to uranium.

Health Effects of Uranium

Previous research has examined and described the human health effects associated with uranium exposure based on toxicological as well as epidemiological evidence. Generally, the health effects of uranium in drinking water, outside of cancer specifically, are considered to be a result of a chemical effect and not from radiation itself (ATSDR 2013). Although most ingested uranium is excreted through the urine and feces, an estimated ~1.5% of ingested uranium is assumed to be absorbed in the gastrointestinal tract in

Table 1. Human health effects of ingested uranium.

Health effect	Low-moderate-high evidence of health effect	Statistically significant ^a	Minimum level of uranium exposure associated with health effect	References ^b
Carcinogenic				
Bone cancer	NA	No	NA	Keith et al. 2013
Colorectal cancer	Low	Yes	1 µg/L	Radespiel-Tröger and Meyer 2013; Wagner et al. 2011
Kidney cancer	Low	Yes ^c	5 µg/L	Radespiel-Tröger and Meyer 2013; Wagner et al. 2011
Leukemia	Low	Yes ^c	1 µg/L	Radespiel-Tröger and Meyer 2013; Wagner et al. 2011
Liver tumor	Low	Yes	10 µg/L	Banning and Benfer 2017
Lung cancer	Low	Yes ^c	1 µg/L	Radespiel-Tröger and Meyer 2013; Wagner et al. 2011
Thyroid cancer	Low	No	>2 µg/L	Canu et al. 2011; van Gerwen et al. 2020
Cardiovascular				
Hypertension	Low	Yes	>1 µg/L	CDC 2012; Hund et al. 2015; Kurttio et al. 2006
Endocrine				
Urinary glucose	Moderate	Yes	3 µg/L	Kurttio et al. 2002, 2006; Zamora et al. 2002
Thyroid function	Low	Yes	>2 µg/L	Banning and Benfer 2017; van Gerwen et al. 2020
Renal				
Nephrotoxicity	High	Yes	>2 µg/L	Banning and Benfer 2017; Brugge and Buchner 2011; Brugge et al. 2005; Corlin et al. 2016; WHO 2017; Kurttio et al. 2002, 2006; ATSDR 2013

Note: Evidence of health effect was measured as follows: low: 1–2 reference studies; moderate: 3 reference studies, and high: ≥4 reference studies that evaluated the health effects of uranium-contaminated drinking water. CI, confidence interval; NA, not applicable; RR, risk ratio.

^aStatistical significance measured as $p \leq 0.05$.

^bOnly human studies listed.

^cKidney cancer was statistically significant only in women [RR = 1.16 (95% CI: 1.00, 1.35), $p = 0.048$], leukemia was statistically significant only in men [RR = 1.28 (95% CI: 1.08, 1.52), $p = 0.004$], lung cancer was found to be statistically significant only in women [RR = 1.12 (95% CI: 1.03, 1.22), $p = 0.007$], (Radespiel-Tröger and Meyer 2013).

adults (Zamora et al. 2002). Uranium remains in the body a relatively short time; however, a bioaccumulation effect of uranium through drinking water may create a bioaccumulation effect of uranium in exposed individuals, leading to the potential for adverse health outcomes. For example, ingested uranium has a half-life in bones of an estimated 70–200 d, with 80–90% of deposited uranium leaving the body after 1.5 y (Wagner et al. 2011; Arzuaga et al. 2015; Banning and Benfer 2017). Uranium that is absorbed by the body is found in its highest concentrations in the bones, liver, and kidneys, with an estimated 66% of the absorbed uranium in the body being found in the bones (Keith et al. 2013).

The majority of current research suggests that chemical toxicity from the intake of small quantities of uranium through contaminated drinking water may cause damage to the cardiovascular system and kidneys (Hon et al. 2015; Ali et al. 2019). Chronic exposure to even small amounts of uranium may be associated with some cancers and, at high exposure levels, kidney disease (Bjørklund et al. 2020). A preliminary overview of several potential health outcomes from ingested uranium via drinking water from human studies is reviewed below and in Table 1. This preliminary review is not meant to serve as a comprehensive etiological or epidemiological review of uranium's health effects, as previously noted, but, instead, as a platform for further discussion on the potential health effects and relevance in AI communities referenced later in this commentary.

Carcinogenic effects. Although uranium exposure has been weakly associated with some cancers, including bone cancer and leukemia, uranium is not currently classified as a carcinogen by the International Agency for Research on Cancer or by the National Toxicology Program (Keith et al. 2013). Most of the potential carcinogenic effects from uranium are thought to be due to acute radiation exposure rather than the chemical effects of ingestion (ATSDR 2013). Several studies since 2011, however,

have described an association between ingested uranium via drinking water and cancer (Table 1). For example, recent ecologic studies have suggested that chronic exposure to uranium in drinking water may be related to an increase in the incidence of leukemia, kidney cancer, and lung cancer in women and colorectal cancer in men (Wagner et al. 2011; Radespiel-Tröger and Meyer 2013).

Banning and Benfer (2017) have described weak yet statistically significant positive correlations between exposure to uranium through drinking water and an increase in the incidence rates of tumors and growths, in addition to liver disease, in Bavarian residents (Banning and Benfer 2017). In addition, a recent study by van Gerwen et al. (2020) stated that although there was no evidence of a significant correlation within the described ecological study, certain states evidenced high age-adjusted thyroid cancer incidence rate in geographic areas that were within close proximity to known uranium-contaminated sites (van Gerwen et al. 2020).

Research investigating environmental uranium exposure and cancer has historically been inconclusive, often using ecologic exposure assessments with inconsistent case definitions and many not having adequately accounted for long latency periods (Canu et al. 2011; Keith et al. 2013). Long-term cohort studies would be a more effective way of assessing the chemical impact of uranium exposure on the development of various types of cancers (Corlin et al. 2016).

Cardiovascular effects. Although there is evidence indicating the potential for cardiovascular effects following the ingestion of uranium, studies are sparse and limited. The potential link between uranium and cardiovascular effects was, for example, supported in a French cohort study where individuals with occupational exposure to uranium were found to have an increased risk of dying from diseases of the circulatory system (Canu et al.

2012). In addition, a survey from the Diné Network for Environmental Health project (on the Navajo Nation), reported that those in close proximity to uranium-contaminated sites were found to have an increased incidence of hypertension (Hund et al. 2015).

In another study, completed in Finland, researchers noted a significant association between urinary uranium levels and increases in diastolic and systolic blood pressure among adults living in households with uranium-contaminated drinking water within the range of 0.03–1,500 µg/L (median daily intake = 36 µg/L uranium/day) (Kurttio et al. 2006); however, the increases in blood pressure were small and were not identified until urine uranium levels were >1 µg/L. A urinary uranium level of 1 µg/L is 25 times higher than the 95th percentile level for the U.S. population (CDC 2012). This research is consistent with findings from Kurttio et al. (2002), suggesting that an increase of 1 mg/L (i.e., 1,000 µg/L) in uranium-contaminated drinking water is positively associated with an increase of 7.4 mmHg (systolic) and 5.0 mmHg (diastolic) blood pressure, respectively (Kurttio et al. 2002). Kurttio et al. (2006) additionally noted that increases in blood pressure were greater in older individuals (>65 years of age) compared with younger individuals with exposures (Kurttio et al. 2006).

Endocrine effects. There is currently a slim research base for uranium's effects on the endocrine system. A few studies have been completed that examined various markers of endocrine function; however, there is, again, need for much more research in this area.

In one study, there was a significant association between uranium exposure and urinary glucose, β2-microglobulin, and alkaline phosphatase levels. This association was evidenced in females and males living in areas with high uranium concentrations in drinking water, ranging from 3 to 570 µg/L of uranium (Zamora et al. 2002; Keith et al. 2013). Another ecological study evaluating the health effects of uranium described a “weak yet significant association” that researchers observed between urinary uranium levels and excretion of calcium and phosphate (Kurttio et al. 2002). That study specifically evaluated 325 Finnish residents who were exposed to uranium in drinking water from bored wells and also found an increase in urinary glucose excretion (Kurttio et al. 2002; WHO 2017). A significant association between cumulative uranium intake and excretion of urinary glucose levels was additionally described by Kurttio et al. (2006). Furthermore, a weak, yet significant, correlation between drinking water and thyroid disease was evidenced with drinking-water uranium concentrations of >2 µg/L (Banning and Benfer 2017). Last, van Gerwen et al. (2020), specifically noted that a higher uranium concentration in drinking water may affect thyroid health.

Renal effects. Nephrotoxicity is one of the most commonly cited and more well-known health effects of exposure to uranium (Brugge et al. 2005; Brugge and Buchner 2011; ATSDR 2013; Corlin et al. 2016). It is thought that uranium's main target in the body is the kidneys because ingesting even low doses of uranium in drinking water may result in kidney effects (ATSDR 2013). Several epidemiological studies have sought to investigate and determine the association between chronic exposure to uranium in drinking water and renal effects (Mao et al. 1995; Zamora et al. 1998; Kurttio et al. 2002, 2006; Seldén et al. 2009; Zamora et al. 2009; WHO 2017). Seldén et al. (2009) found that urinary uranium concentrations are weakly associated with renal damage, whereas Zamora et al. (1998) found adverse effects from uranium on the proximal tubule but not the glomerulus. Last, a review by Vicente-Vicente et al. (2010) suggested that nephrotoxicity may be the result of exposure to a high-level acute exposure rather than to chronic low-level repeated exposures of uranium.

Regardless, more research is clearly needed on the relationship between uranium exposure and potential renal effects. This is made more prominent given the expanding knowledge on the potential for epigenetic effects, which to date has been relatively unexamined.

American Indian Considerations

With AI populations already facing continued and progressive economic and social marginalization, higher prevalence of chronic diseases, and systemic discrimination, the associations between various toxicant exposures, including uranium and various chronic conditions, is in need of further examination (Meltzer et al. 2020). Considerable health disparities exist between the AI and the general U.S. populations (CDC 2013). The health disparity and risk factor burden for AIs are multi-faceted—low incomes, low high school graduation rates, high rates of commercial tobacco use, poor nutrition, and environmental exposures, among others—all noted to be structurally rooted within the continued effects of colonization (Warne and Lajimodiere 2015). These social, ecological, and colonial determinants of health combined with a severely underfunded health care system have led to decreased access to health care services and among the highest incidences of preventable diseases in the United States (Warne and Frizzell 2014). With this, preliminary studies have started to explore uranium's health impacts on AI populations; however, studies are geographically limited and sparse. In the limited studies that have been done with AI populations to date, some concerning findings are in need of further exploration.

In members of the Navajo Nation, proximity to abandoned uranium mines strongly predicted endothelial transcriptional responses to their serum, including chemokine ligand 2, vascular cell adhesion molecule-1, and intercellular adhesion molecule-1 ($p < 0.0001$ for each), even after controlling for all major effect modifiers (Harmon et al. 2017). In another Navajo area study, contaminants (i.e., primarily uranium, arsenic, and radium) derived from uranium mine waste enhanced development of autoantibodies in some individuals, indicating that specific autoantibodies may be a sensitive indicator of immune perturbation by environmental toxicants (Erdei et al. 2019). Such data demonstrates a potential for increases in inflammatory mediators on exposure to uranium that to date have largely been unexplored. These potential inflammatory mediators have also not been considered in current drinking-water standards or regulatory risk assessment evaluations (Erdei et al. 2019). This developing research on the potential inflammatory triggering processes of uranium are platformed on an already higher known risk of some autoimmune (i.e., inflammatory) conditions in AI populations (Peschken et al. 2010; Scally et al. 2017; Scofield et al. 2020).

American Indians also have the highest prevalence of diabetes in all racial and ethnic groups in the United States (McLaughlin 2010). Kidney disease, a complication of poorly controlled diabetes, is 2-fold higher in AIs compared with White Americans (Hall et al. 2011). Given uranium's predilection for the kidneys, the effects on the progression of diabetic kidney disease in susceptible AI populations has not been examined. Synergistic effects for the development of diabetic-related kidney disease among AIs living on reservations with known exposures to uranium cannot be ruled out. This effect may also be compounded by additive toxicant exposure that is also thought to increase the risk of developing diabetes, such as arsenic (Huang et al. 2011), which has been found within areas of abandoned uranium mines, particularly on the Navajo Nation (Hoover et al. 2017). Because uranium is known to cluster with other minerals such as arsenic in

groundwater, implications for the examination of synergistic health effects is in need of further examination (Pang et al. 2016).

Considerations for how epigenetic effects from environmental exposures may contribute to increased rates of disease presentations in AI populations have not been investigated to date. This is despite the increasing and ongoing research in animal models demonstrating the potential for multigenerational epigenetic health effects from low-dose uranium exposure (Elmhiri et al. 2018; Legendre et al. 2019). With developing technologies in the field of epigenetics, future research in this area could elucidate transgenerational risk factors that have yet to be formally identified in humans.

With increased cancer risk being a possible sequela of chronic uranium exposure, determining true causation in population health studies is fraught with difficulties due to their observational nature and ability to suggest mere association. Population health research and clinical decision-making relies on the accurate collection of data, which is also difficult in reservation communities (Bauer and Plescia 2014). For example, in South Dakota, 70% of AIs die before reaching 70 years of age, compared with only 25% of Whites (Christensen and Kightlinger 2013), yet for the years 2013–2017, the National Cancer Institute's Surveillance, Epidemiology, and End Results Program, reported the median age of cancer diagnosis in the United States as 66 y (National Cancer Institute 2020). So with this, AI populations' cancer risk and prevalence data may therefore be shadowed in states such as South Dakota because of the population dying of other causes at an earlier age in life (e.g., suicide, unintentional injuries). Although there are other considerations in regard to the prevalence of cancer in tribal communities (e.g., the lack of solid baseline prevalence data from which to develop comparisons, overall lack of cancer surveillance, lack of available hospital infrastructure), the ability to study or clinically diagnose the etiologies of conditions such as cancer with higher prevalence in the aged becomes more difficult in populations who have lower average mortality rates. In addition, AI populations in general (although variations do exist per region) have the highest smoking rate of any racial or ethnic group (American Lung Association 2019), which is an independent risk factor for cancer morbidity and mortality. Reporting rates are also thought to be underestimated owing to the difficulty in data collection in tribal and rural areas, which makes statistical control more difficult to rely on in observational studies (Pearson et al. 1994). Therefore, given the multitude of complex factors impacting cancer reporting in AI communities backboned on a lack of infrastructure and coupled with inequities in mortality rates, effective and rigorous cause-and-effect research on reservations can be difficult when it comes to toxicants.

Data limitations as noted are a consistent concern for tribal areas within the United States. With data limitations (for both health and environmental data) and accessibility issues, the ability to properly study AI population risk from uranium exposure from drinking water on reservations is challenged. Independent water quality reporting has sometimes been done and published due to the otherwise lack of ongoing water testing in a respective region. This includes work by such groups as the Defenders of the Black Hills in South Dakota (DBH). In one DBH-sanctioned report, it was stated that long-term ingestion of one local water source could lead to cancer incidence based on the levels of radiation present in the test sample from the Pine Ridge Indian Reservation and based on the reported water quality levels (White Face 2011). DBH strongly recommended that the community consider distilling all the water that comes from the wells serving the Pine Ridge Indian Reservation in addition to consulting with nuclear health professionals regarding the health

consequences of high gamma radiation, remediation for radon in the water, and possible contamination of the pipelines serving the communities (White Face 2011). From one author's experience being originally from the Pine Ridge Indian Reservation, many families in this community are still drinking water from their wells, and it is unclear if mitigation was able to proceed due to various barriers to the mitigation process that are discussed in this commentary. As noted previously, the overlapping jurisdictional issues across tribal and federal governments further complicates mitigation processes such as that on the Pine Ridge Indian Reservation.

Discussion

Uranium Public Health Policy Recommendations

Overall, we have seen a serious and immediate need for better coordination of uranium-related water testing, reporting, and mitigation efforts in addition to more support for the implementation of best practices in tribal communities in the United States. We therefore propose that the following seven policy recommendations should be operationalized to ensure reservation communities at risk of uranium and related exposures do not continue to suffer continued health disparities due a preventable public health risk:

Increase funding for drinking-water quality monitoring and infrastructure on tribal lands. Tribes currently have various sources of water-quality monitoring funding from federal agencies. The U.S. EPA offers several programs, including funding through the CWA Section 106 Water Pollution Control, CWA Section 319 Nonpoint Source Pollution Control, CWA Section 104(b)(3) Wetlands Grants, and the CWA Tribal Set-Aside grant program. As of 2020, the U.S. EPA typically awards grants between the amounts of \$40,000 and \$200,000, with first-time applicants eligible for \$40,000 grants (U.S. EPA 2020e). In 2019, the U.S. EPA announced that it was offering \$2.5 million to restore and protect water quality in a competitive grant process for the 574 tribes, which would equate to ~\$4,355 per tribe if split evenly; however, the maximum project budget was \$100,000, which would mean full funding for only 25 tribes if the maximum amount was requested by 25 tribes, consequently leaving out 549 tribes (U.S. EPA 2019). Tribes have, therefore, continuously advocated for more funding for water-quality testing and monitoring for their regions given the various barriers in place in accessing the current grants available.

Several different limitations exist that prevent tribes from competing for the grants available to ensure safe drinking water for their communities. For example, for first-time U.S. EPA applicants as noted above, \$40,000 to start a water-quality monitoring program in a community could be very challenging. From what we have seen, the ability to sustain one employee to ensure viability of the program becomes very difficult with small funding pots. Furthermore, 574 tribes must often compete against one another for grant funding, as noted in the U.S. EPA funding example above, and it is very difficult when a tribe is just beginning and lacks dedicated personnel. Tribes will often bundle grants to allocate funding for one to three full-time employees; however, the responsibility for all environmental regulation is then placed on those very limited employees.

The allotted resources to IHS and the tribes from the federal government for water infrastructure are severely underfunded (U.S. Government Accountability Office 2018). For the fiscal years 2018 and 2019, \$133,000 was allotted to U.S. EPA Region 8, which includes over 400,000 AIs, 32 federally recognized tribes across four IHS areas in the six states of Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming

(U.S. EPA 2020f). This amount, in our opinion, is completely inadequate to ensure that AI communities in this region have access to adequate infrastructure to ensure safe drinking water. Due to underfunding not being reservation specific, there is urgent need to ensure that tribes across the United States have the available infrastructure to adequately test and monitor their drinking-water supplies to ensure levels safe for health and development. When uranium is detected in any drinking-water source, mitigation efforts add an additional cost layer on an already overburdened system.

Costs associated with uranium mitigation can be substantial. Removal of uranium can be achieved during water treatment by trained personnel using a mixed bed containing 10% strong base anion resin (Clifford and Zhang 1994; WHO 2012). Individuals may also use a reverse osmosis home unit, which has also been shown to be effective in the removal of >99.9% of uranium from initial concentrations (WHO 2012).

The ability to both treat and mitigate uranium exposure is dependent on the budget available to test and then deal with the contaminant. In-home reverse osmosis systems, for example, can range from a few hundred to several thousand dollars depending upon the type, size, and installation requirements [e.g., a one water tap point-of-use reverse osmosis system can remove an estimated 90–98% of uranium from drinking water and can cost an average of \$550 per household for the unit plus costs for annual filter replacement (U.S. EPA 2007)], with larger water system mitigation units serving communities costing anywhere from \$500,000 to millions of dollars, depending on upon the severity of contamination. The mitigation strategies noted here have real and often unattainable costs structures for members of tribal communities. Yet, with uranium consumption in drinking water being entirely preventable with the available resources, from our perspective, there is no reason why tribal communities should continue to have uranium in their drinking water no matter the source.

The federal government must ensure resources are sufficient to guarantee that all Americans have access to clean drinking water in this country in keeping with the United Nations Resolution 64/292 explicitly recognizing the human right to clean drinking water (Office of the High Commissioner for Human Rights 2011). In our opinion, simple measures such as increasing the funding to account for uranium release from existing sources (e.g., mining activities) can assist in filling data gaps that would make it easier to focus in on high-priority sites for more efficient resource and mitigation planning. We feel there is much work to be done to ensure safe drinking water for all AI communities in the United States.

Remove the need for tribally matched financial funding for water-related grants from the federal government. In our opinion, requiring tribal governments to have matched funding available to receive federal grants to ensure the safe access to drinking water is a violation of the fiduciary responsibility to AI communities outlined in hundreds of treaties between tribal nations and the U.S. government. For example, Article IV of the 1868 Fort Laramie Treaty with the Sioux Nation states that “The United States agrees, at its own proper expense, to construct, at some place on the Missouri River, near the center of said reservation where timber and water may be convenient” (Sherman et al. 1868). With AI communities having the highest poverty rate among all minority groups in the United States (Poverty USA 2018), tribal governments often do not have the ability to meet the financial match percent required to even apply for many of the grants available. This financial match requirement not only precludes many AI communities from being able to apply, but it also continues to ensure that a portion of the U.S. population

does not have access to clean and safe drinking water. We, therefore, recommend that the federal government, or any of its granting agencies, remove the need for, or add an exception to, the tribally matched financial funding requirement for water-related grants.

Increase the availability and assistance for testing tribal drinking-water sources. We propose that the criteria and processes for monitoring uranium contamination of drinking water should be more efficiently supported through formal assistance programs that will better facilitate the ease and ability to test according to best practice standards in tribal nations. Tribal water should be regularly sampled to determine the suitability for drinking water, with special emphasis on water sources that are not currently well monitored (i.e., wells on tribally owned and occupied land). This will only be possible with the right support in place for personnel, training, and access to adequate funds as previously noted. In addition, drinking water on tribal lands should be sampled not only for major ions, trace elements, and uranium but also for uranium isotope ratios (U-238:U-235) as an indicator of uranium redox reactions that control the mobility of uranium and have implications for adequate risk assessment (McMahon 2010).

Given that many tribal community households rely on unregulated and unmonitored wells for their water supply, the existing wells would need occasional monitoring in combination with the launch of formal education campaigns for residents on the importance of well testing. We feel that funds should be made available for this purpose, and, if the well-water supply is adequately characterized and measured concentrations of uranium in addition to other potentially relevant contaminants and proxies (e.g., arsenic) are consistently below screening levels, then sampling frequency may be reduced. Regional- or state-level uranium contour maps may also aid in the delineation of nearby sources of uranium contamination in need of higher levels of screening. If sources of potential uranium contamination exist nearby or are expected to be changing rapidly with time, then the sampling should increase in frequency (WHO 2017). Long-term stability of the respective uranium plume identified in the respective drinking-water aquifer should also be monitored (i.e., its redox state) over time to better predict whether uranium sources are likely to change rapidly, which could affect testing frequency.

Sampling frequency should be maintained or increased if uranium concentrations approach the guideline levels of 30 µg/L or if the sum of ratios of the observed concentrations of individual radionuclides are equal to their guidance levels (WHO 2017). The World Health Organization (WHO) recommends developing a graded approach to sampling frequency commensurate with the degree of contamination, the source of supply (i.e., surface water or groundwater), the size of the population served, the expected variability of radionuclide concentrations, and the availability and results of historical monitoring records (WHO 2017). International standards are available related to the assessment of radiological water quality, including sampling procedures (e.g., preservation and handling of samples) and programs.

Support the creation of an accessible tribal drinking water and environmental health library of information. Having a formal access point for drinking water and other environmental-health resources (such as regional-scale uranium contour maps) that are applicable to the needs of tribal organizations and communities would be of great value. Although there are some repositories of information currently available, such as the U.S. EPA’s Ground Water and Drinking Water website (<https://www.epa.gov/ground-water-and-drinking-water>), gaps remain in the accessibility of the materials and their relevance to tribal community needs across the country. We feel that formal support for the

Table 2. Guideline values for uranium in drinking water.

Location	Guideline for uranium in drinking water	References	Regulating agency
Australia	17 µg/L	NHMRC and NRMCMC 2011	Australian Government
Canada	20 µg/L	Government of Canada 2018	Health Canada
Germany	10 µg/L	Banning and Benfer 2017	German Government
USA	30 µg/L	WHO 2017	World Health Organization
Regions adhering to WHO recommendations	30 µg/L	WHO 2017	World Health Organization

Note: All units for guideline values of uranium in drinking water are measured in micrograms per liter. WHO, World Health Organization.

creation of an accessible tribal drinking water and environmental health library of information, including resources related to contaminants, is needed. By creating a consistent access point (potentially in an already established organization with connections to nationwide tribal communities), tribal communities could have a shared repository with up-to-date information and materials that would then help ensure communities can be more proactive in their prevention and mitigation efforts.

Lower the guideline values for uranium in drinking water on tribal lands. Although some areas of the world are decreasing their guideline values for uranium, it is important to note that the WHO guideline values for uranium in drinking water have increased significantly in the last two decades. In 1998, the WHO guideline value was 2 µg/L, and this was raised to 15 µg/L in 2004, and to 30 µg/L in 2011 despite concerns raised on the potential health implications with this increase (Frisbie et al. 2013). The United States currently has a guideline value of 30 µg/L of uranium allowed in drinking water, which was last updated in 2011 (WHO 2017). Guideline values for uranium in drinking water have, therefore, increased by a factor of 15 within a period of just 13 y (Ansoberlo et al. 2015). In 2015, the U.S. EPA did seek to make improvements by lowering the guideline levels for uranium in drinking water in addition to including additional monitoring requirements of *in situ* recovery mining sites that are known sources of uranium in groundwater (U.S. EPA 2015b). The 2015 proposed rule sought to amend and improve the current rule (U.S. EPA 2015b); however, these proposed rules for additional monitoring requirements were not finalized. In 2017, another proposed rule that sought to propose additional WQS was also withdrawn (U.S. EPA 2020b). Although both proposed rules had inadequacies, they were an improvement over the existing requirements.

In the United States specifically, the U.S. EPA, under the authority of the SDWA, has set the MCL goal for uranium at 0 µg/L (U.S. EPA 2020c). This is a health-based goal for which there are no known or anticipated adverse effects on human health; however, levels of uranium in drinking water above zero are not enforced given that they are, again, merely a goal. For enforcement, the U.S. EPA follows the guideline values set by the WHO at their MCL for uranium in drinking water at the level of 30 µg/L (U.S. EPA 2015a) (Table 2).

As noted, some countries have lowered the guideline values for uranium in drinking water, including the German state of Bavaria, which now has a guideline value of 10 µg/L, which has been valid since 2011 (Banning and Benfer 2017) (Table 2). Given the many unknown health effects from the ingestion of uranium, including the potential for transgenerational epigenetic effects and the already high baseline level risk for kidney disease among AI populations, we feel that a reexamination of uranium reference levels on tribal lands is needed. Tribal communities have the potential to lead the way in the United States by setting evidence-based standards that reflect the potential risk to the community, and we can also look to examples such as the German state of Bavaria with its operationalized guideline of 10 µg/L.

Improve drinking-water quality monitoring and data access. Given the Indian self-determination laws existing in the United

States (i.e., the Indian Self-Determination and Education Assistance Act of 1975), certain tribes have elected to take responsibility for functions and operations on their reservation lands, including the setting of WQS and the consequent enforcement of those standards (U.S. Department of the Interior: Indian Affairs 2020). Each tribe in the United States, however, has varying levels of capacity for delivering drinking water to their members and varying levels of ability to take over water quality management in general, with wide variations existing. From our experience, some tribes have their own water utility or wells, some tribes rely on the local municipality utility, and many tribal members rely on unmonitored and unregulated well sources of drinking water. Many of the tribes work with the IHS to develop water infrastructure. As of 2019, the IHS has a backlog of 1,837 sanitation facilities construction projects at a cost of ~\$2.7 billion to provide American Indian and Alaskan Native communities with safe drinking water and adequate sewer systems in their homes (IHS 2019).

The IHS assists many tribes with drinking-water capacity and, as noted, some tribes have their own water operators to monitor and maintain safe drinking water. Currently, the accessing of up-to-date water quality reports from the IHS is a complicated process that can be improved. Reports can often be difficult to interpret for communities without formal training in how to read such reports. We therefore call for the IHS to improve the ease of public access to drinking-water reports in addition to increasing the accessibility of data reports by ensuring various skill levels can interpret and understand the data being reported from drinking-water tests being completed in tribal areas.

Increase research and research capacity on environmental health topics within tribal communities. Limited research exists outside of certain active mining sites and geographic regions in the United States on the human health effects from the exposure of uranium through ingestion. The majority of the research to date has focused on large body system effects (e.g., cardiovascular, kidney, cancer), with an increased need for more research in specific areas such as immune-modulating effects, epigenetic effects, endocrine effects, and diabetic additive effects from exposure to uranium through ingestion in AI populations.

There is also an overall greater need for increased collection of ecologic and epidemiologic-specific data in relation to uranium's health effects which should be performed and synthesized in partnership with tribal communities. We feel that working directly with tribal communities will help ensure greater potential for capacity building in drinking-water quality testing, monitoring, and mitigation efforts with self-determined programming options made possible for both containment and public health efforts nationally.

Conclusions

Uranium contamination of drinking-water sources on AI reservations in the United States is a largely ignored and underfunded public health crisis. With an already marginalized population, we feel that the potential for adverse health effects and outcomes are multiplied. We are firm in stating that stakeholder engagement and

organizational support will be needed for successful mobilization of skills and resources to ensure immediate adoption and implementation of the stated policy recommendations. Special attention should be focused at multiple levels of government to ensure clean water for all Americans, including those in tribal communities.

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