Uranium Mining Impacts in the Grand Canyon Region

Stephen Maples • Grand Canyon Class • Winter, 2016

Introduction

The legacy of uranium mining and the atomic era in the United States was born and will likely end in a small corner of the Southwest. The richest uranium reserves in the United States are found on both the North and South Rims of the Grand Canyon, and much of the uranium used for nuclear weapons and for nuclear power generation in the US was mined from this region. The legacy of these mining and milling operations remains an environmental challenge for several human and ecological communities within the Colorado River watershed area. Uranium and its byproducts remain hazardous to humans and environment over thousands of years, creating a unique and remarkably challenging problem for scientists, engineers, and decision makers. Interestingly, the final disposal location for much of the spent uranium used in nuclear power generation may end up within 150 miles of the Colorado River at Yucca Mountain, NV. For the Colorado River watershed community, the lifecycle of uranium will come full circle, and ironically, much of the uranium removed from the ground in this region will likely end up back in the ground, not too far away.

The U.S. Dept. of Interior (DOI) recently placed a 20-year moratorium on new uranium mining claims on over 1 million acres of public land in three 'segregation areas' in the Grand Canyon region (Fig. 1). Despite strong demand for domestically mined uranium, DOI enacted the moratorium due to potential impacts of dissolved uranium and other heavy metals on groundwater that discharges to the Colorado River and to adjacent springs. The decision was applauded by a broad array of interest groups, including environmentalists and Colorado River water users in Southern California. Some localized elevated concentrations of uranium in the Grand Canyon region have been found to occur naturally, so it can be difficult to definitively determine whether increased concentrations in mining areas are naturally-occurring or from mining impacts (Alpine, 2010).

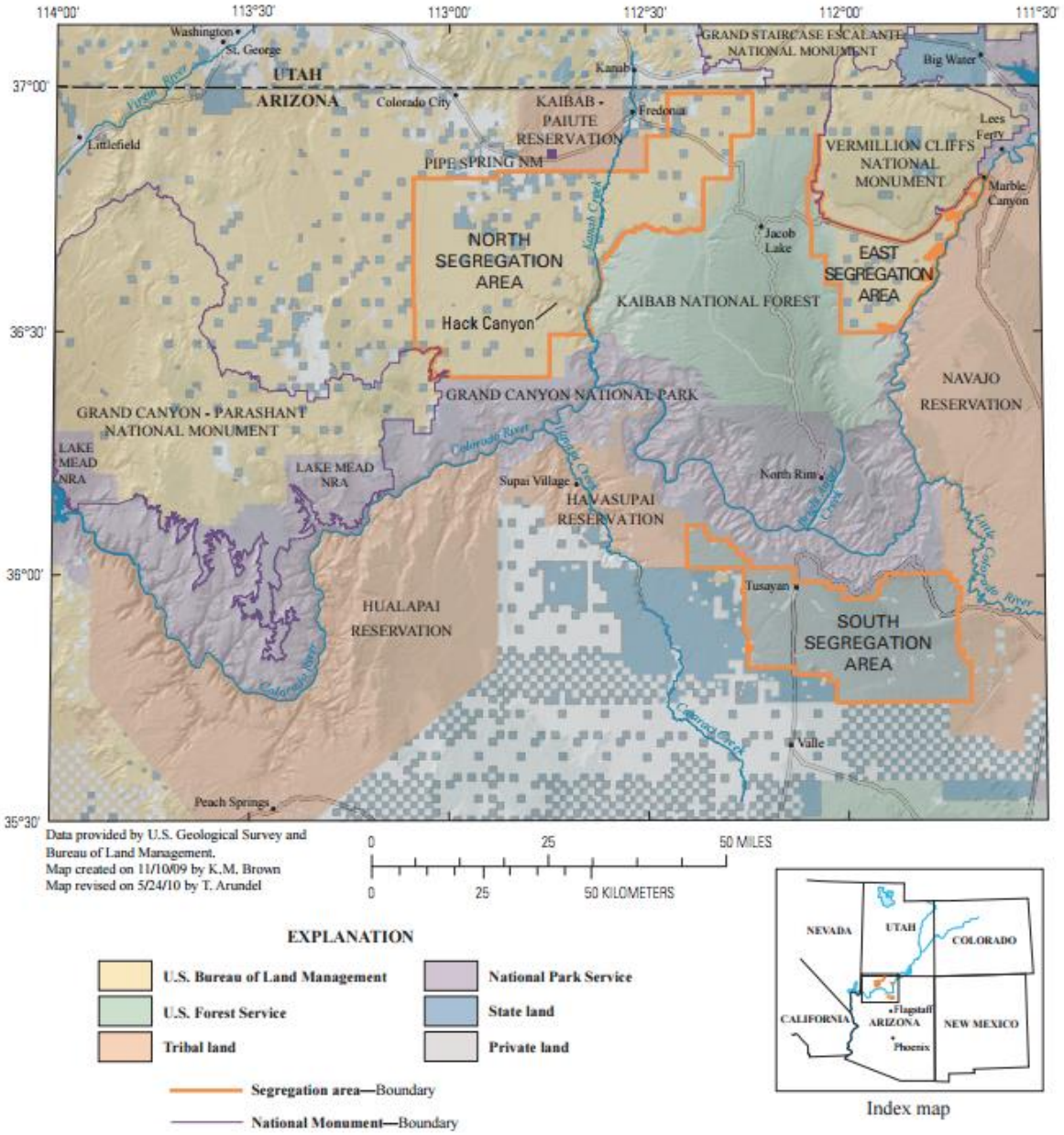

Fig. 1: Uranium mining segregation areas in the Grand Canyon region (Alpine, 2010)

Uranium Background

Uranium is the heaviest naturally occurring element on Earth. Henri Becquerel first discovered the radioactive properties of Uranium in the late 1800s and Marie Curie further explored this unique property, inadvertently discovering radium and polonium, byproducts of uranium radioactive decay. Despite its unique properties, uranium had little commercial value until the advent of the atomic age in the 1940s. Uranium isotopes come in three flavors: U-238 (99.3% abundance), U-235 (0.7% abundance), and U-233 (< 0.01% abundance). The half-life of U-238 is about 4.5 billion years. What makes uranium especially important for weapons and nuclear power is that it is naturally fissile, meaning that in addition to its radioactive properties,

when a uranium atom is bombarded with energy it splits into smaller pieces (fission products) and releases 400 times the activation energy required to split the atom. U-238 is fissile, but it cannot sustain its own fission. U-235, on the other hand, can self-sustain fission once initiated. The ratio of U-235 and U-238 largely determines whether the uranium can either release large amounts of energy very quickly (i.e., in a nuclear weapon), or relatively slowly (i.e., to power a steam turbine in a nuclear power plant). Highly enriched uranium for nuclear weapons is >90% U-235, and low-enriched uranium is 3–5% U-235.

The difference between natural radioactive uranium decay products and anthropogenically-derived fission products is important for radioactive waste disposal considerations. Decay products (e.g., radium, radon, polonium, thorium) are varyingly radiogenic and toxic, but are all found naturally on earth. Fission products (e.g., iodine-131, strontium-90, cesium-137, etc.), on the other hand, number in the hundreds and are the sole product of nuclear testing. Each fission product behaves similarly to its stable-isotope sister element, which makes some especially dangerous. Stable iodine (iodine-127), for example, preferentially concentrates in the thyroid; when iodine-127 is replaced by radioactive iodine-131, the thyroid can be damaged by highly localized beta and gamma emissions. The radioactive properties and toxicity of both uranium decay and fission byproducts are considered for final disposal of nuclear wastes. Strontium-90 and iodine-131 are considered the most dangerous fission product found in the high-level waste once destined for the now-defunct Yucca Mountain Nuclear Repository. As part of the permitting process for Yucca Mountain, the EPA determined that 10,000 years is required for these byproducts to decay to the radioactive level of uranium. Thus, 10,000 years was the safety design life required for the Yucca Mountain permitting process.

Grand Canyon Region Uranium Mining History

The Grand Canyon region has an active mining history, with several prominent historic mining operations within the park's current boundaries, all of which were developed before the Park's inception. The most historic and prominent of these is the Orphan Mine. Well-known for its proximity Maricopa Point and the Bright Angel Trail, the Orphan Mine was the richest uranium mine in the Grand Canyon region, producing over 4 million pounds of uranium ore during 1953-1969. The mine was originally established as a copper mine in 1893, and is currently the likely source of elevated dissolved uranium concentrations in adjacent springs (Alpine, 2010). Thousands of uranium mining claims have been staked outside the park boundaries, but within the Grand Canyon region. From the 1980s to present, over 23 million pounds of uranium ore have been mined from nine underground operations in the region (Spencer and Wenrich, 2011).

Grand Canyon Region Mining Impacts (The Cradle)

High concentration uranium deposits are abundant in the Grand Canyon region due to unique geologic features—breccia pipes. Breccia pipes are vertical, rubble-filled dike structures that intersect the mostly horizontal sections of Colorado Plateau strata. They are formed

through dissolution and subsequent collapse of karstic strata, which creates vertical, rubble-filled preferential pathways for enhanced migration of mineral-rich geothermal water. Over time, precipitation of these minerals (including uranium oxide) fills the cavities, leaving behind localized, highly concentrated metal ores (Fig. 2). There are over 1300 known breccia pipes in the Grand Canyon region, and all major uranium mining operations in the region are associated with these features (Alpine, 2010).

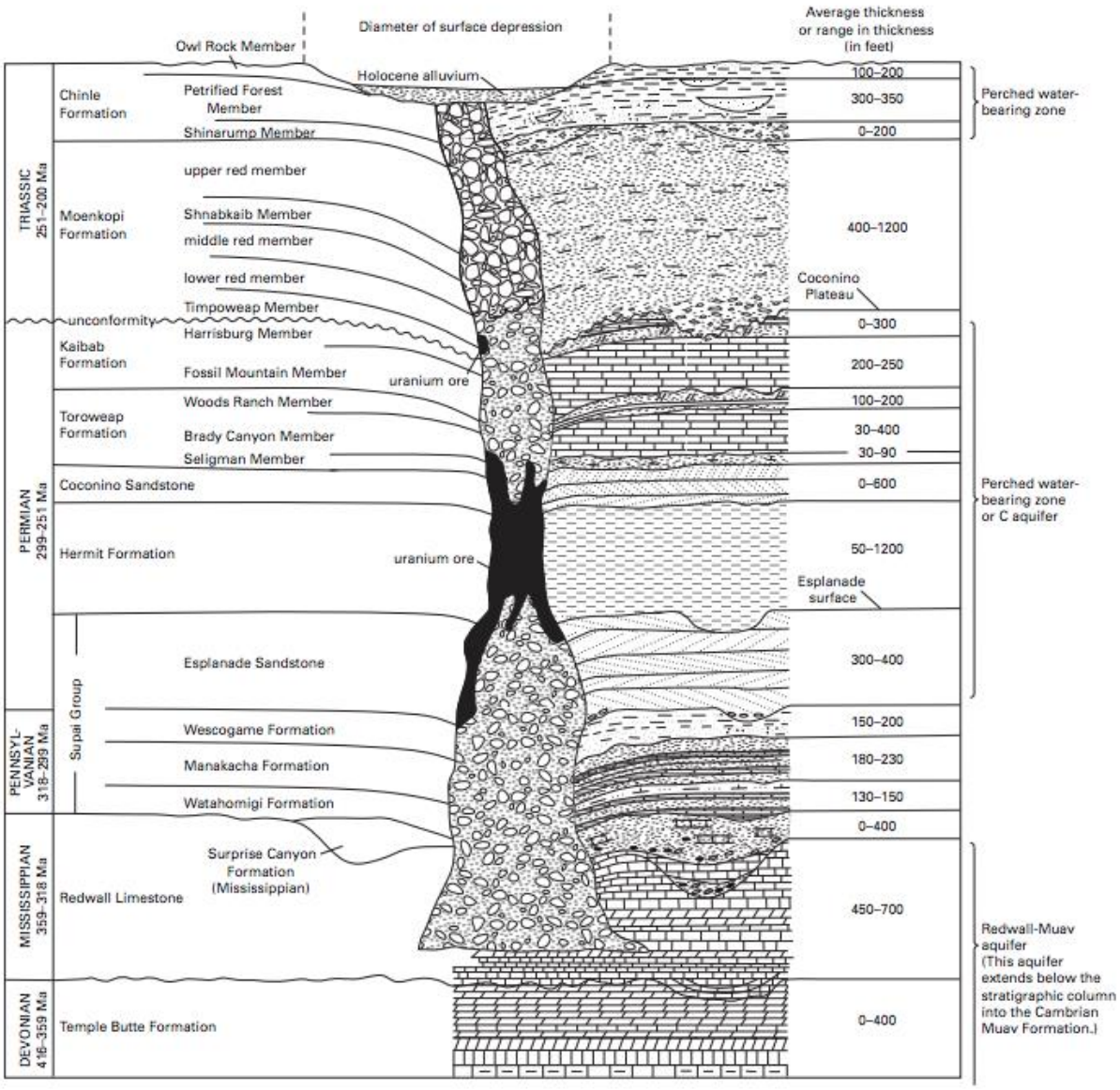

Fig. 2: Conceptualization of breccia-pipe geologic structure (Alpine, 2010).

As part of the BLMs deliberations on whether to close the three Grand Canyon segregation areas to future uranium mining, the USGS was tasked with determining the historical impacts of uranium mining on soil and water quality in the region (Alpine, 2010). A comprehensive synoptic sampling of water chemistry for over 1000 water sources (springs,

wells, stream, and mining features) was conducted on both the North and South Rims of the Grand Canyon (Alpine, 2010). The study found elevated dissolved uranium concentrations, both above background (~5 µg/L) and some above the EPA MCL (30 µg/L), at sites with and without historical mining impacts (Fig. 3). These findings indicate that elevated concentrations of dissolved uranium in water are sometimes naturally occurring due to proximity to breccia-pipe deposits. However, all historical mining sites showed elevated concentrations of dissolved uranium in some form. Below are findings from some of the historical mining sites:

- *Orphan Mine* – Elevated uranium concentrations above the EPA MCL were measured consistently at Salt Creek Spring (average of 30.6 µg/L). Several samples from Horn Creek and Horn Spring were one order of magnitude greater than the EPA MCL (312–400 µg/L). Both springs are hydrologically linked to the Orphan Mine.

- *Canyon Mine* – A nearby well showed wide-ranging, but mostly elevated dissolved uranium concentrations in the eleven samples collected during the study period(range: 4.1–309 µg/L).

- *Hermit Mine* – The highest dissolved uranium concentrations in the study were measured in the underground water in the sump and shaft of the mine (3,310–36,600 µg/L). Although these were measured within the actual mine features, where highly elevated concentrations would be expected, concentrations of this magnitude could constitute an obvious pollution-source if connected to the local or regional groundwater system.

- *Pigeon Mine* – A mine sump sample was collected only once, but showed a 170 µg/L concentration.

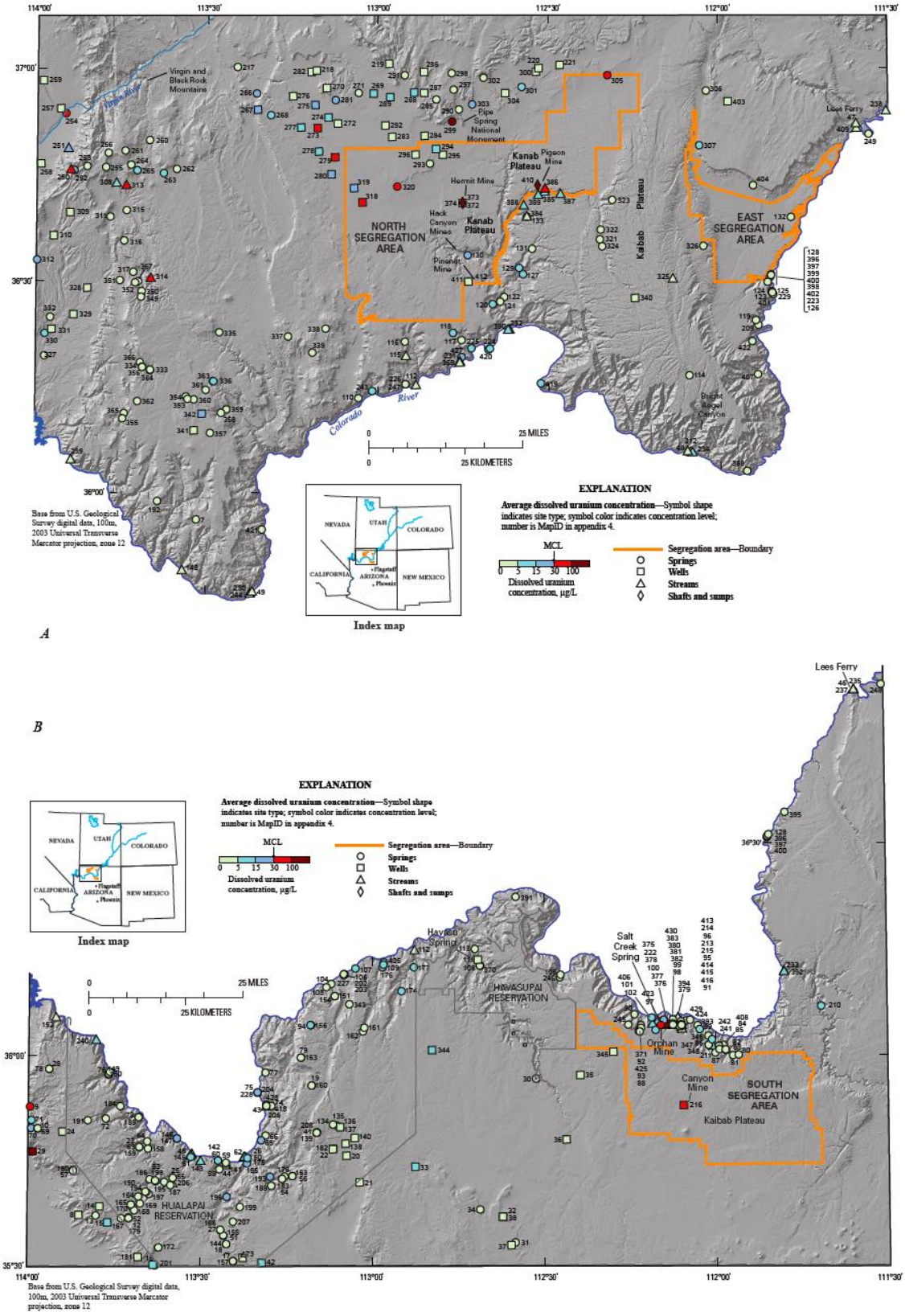

Fig. 3: Sampling locations and average concentrations of dissolved uranium in springs, wells, streams, and mine features along the (*A*) north and (*B*) south rims of the Grand Canyon (Alpine, 2010).

Colorado River water samples collected during the study averaged around 5 µg/L. Given the very large volume of the Colorado River relative to most incoming springs that may be impacted by historical uranium mining, it is unlikely, but as yet unsettled whether local contamination issues from historical mining would have a significant impact on Colorado River concentrations.

Incidentally, geologists from the Arizona Geological Survey (Spencer and Wenrich, 2011) attempted to allay fears of uranium mining impacts by outlining a hypothetical, worst-case scenario in which an entire truck-load of high-grade uranium ore is spilled directly into the river. Given the huge dilutive capacity of the river, their simple calculations suggested an increase in downstream dissolved uranium concentrations from 4.00 µg/L to 4.02 µg/L over the course of a year. Of course, this scenario makes many large assumptions and should be treated as a thought experiment rather than a rigorous scientific exercise.

Grand Canyon Region Milling Impacts (The Interim)

During the mining process, high-grade uranium ores are brought to the surface where they are subject to weathering and transport processes at the land surface. This greatly increases the risk of human and environmental exposure to uranium and other constituents. Even for high-grade deposits, uranium ore is typically comprised of < 1% elemental uranium by volume. Thus, additional chemical processing—milling—of the ore material must take place. Historically, milling operations in the Grand Canyon region took place at, or near, the mine site to minimize transport costs. The milling process typically involves crushing and pulverizing of ore-bearing rock to maximize surface area of the material. Crushed rock is then piled on leach pads, and leaching agents like sulfuric acid are applied to the piles and allowed to permeate through the ore. Depending on the ore chemistry of the rock, different leaching agents are used, with the goal of dissolving as much of the uranium, which is then collected as a dissolved liquid. Further chemical processing removes other dissolved constituents and further concentrates the ore into what is colloquially referred to as yellow-cake uranium.

The milling process is not 100% efficient, and some residual uranium is left behind in the waste rock. In addition, chemical leaching agents are often not fully recovered from the waste rock. Both the residual uranium (and its decay products) and the chemical leaching agents can be long-lived environmental hazards if not managed properly. In addition to the uranium, decay products like radium-226, thorium-230, and radon-222 gas are continually produced during the decay process. Even though radon and radium have relatively short half-lives, the parent isotopes (uranium and thorium) have much longer half-lives, rendering uranium mill tailings dangerous to human health, to some degree, on time-scales of thousands to tens-of-thousands of years (Flint et al., 2001). In the Grand Canyon region there are several examples of poorly-managed milling operations that released radioactive and chemical wastes into the environment. Clean-up is ongoing for many of these sites, often with very high associated costs.

The Moab Mill Tailings Pile, UT:

The Moab Mill tailings pile (a.k.a., the Atlas Uranium Mill) holds the radioactive and toxic mill waste associated with a large-scale uranium mining operation near Colorado River in Moab Utah. The mill processed ore from the early 1950's until 1984, and ultimately disposed of 16 million tons of radioactive tailings in a waste pile over 90 ft tall immediately adjacent to the Colorado River. Ammonia was used as part of heap-leaching operations to extract uranium from ore. Since the mill's closure elevated ammonia and dissolved uranium have been measured in the Colorado River adjacent to the site. It has been shown that elevated ammonia concentrations stem from mill leachate.

In 2001, ownership of the mill and waste pile were transferred to the US DOE, and a plan was set in place to develop an alternative disposal location to mitigate ammonia and uranium impacts on the Colorado River. The plan, named the Uranium Mill Tailings Remedial Action Project (UMTRA), has relocated 48% of the 16 million tons of tailings to a new disposal location 30 miles away from the river (USDOE, 2015). Waste is removed, one truck-load at a time, and transported via rail car to the new site, at a cost of $780 million. In addition to waste-removal, a series of groundwater wells have been emplaced between the tailings pile and the river to intercept migrating dissolved uranium and ammonia (Fig. 4). To date, > 800,000 lbs of ammonia and 4,500 lbs of uranium have been intercepted before reaching the river. The expected project completion date is 2025.

Fig. 4: Aerial view of the Moab Mill tailings pile and well field (USDOE, 2015)

The Church Rock Mill Spill, NM:

The Church Rock uranium spill took place at the United Nuclear Corp. Church Rock mill site on the Navajo Nation in New Mexico on July 16, 1979. During the accident, a dam holding back a pond of liquid uranium mill waste was breached, releasing 93 million gallons of liquid waste into the Puerco River, a tributary to the Colorado River. The liquid waste was highly acidic (pH of 1.2) and contained high levels of radioactive uranium, thorium, radium, and polonium, among others. Ultimately, more radiation was released as part of the Church Rock incident (1.7 TBq) than was released during the Three Mile Island accident, which also took place in 1979. Immediately after the accident, gross radioactivity in the river was 7000x background in Puerco River, and 1700 people lost access to drinking water for some time. Long-term impacts include radionuclide contamination of a shallow groundwater aquifer (Fig. 5). Cleanup of the site is currently overseen by the EPAs Superfund Project, which has removed 175,000 cubic feet of radium-contaminated soil from the site (USEPA, 2014).

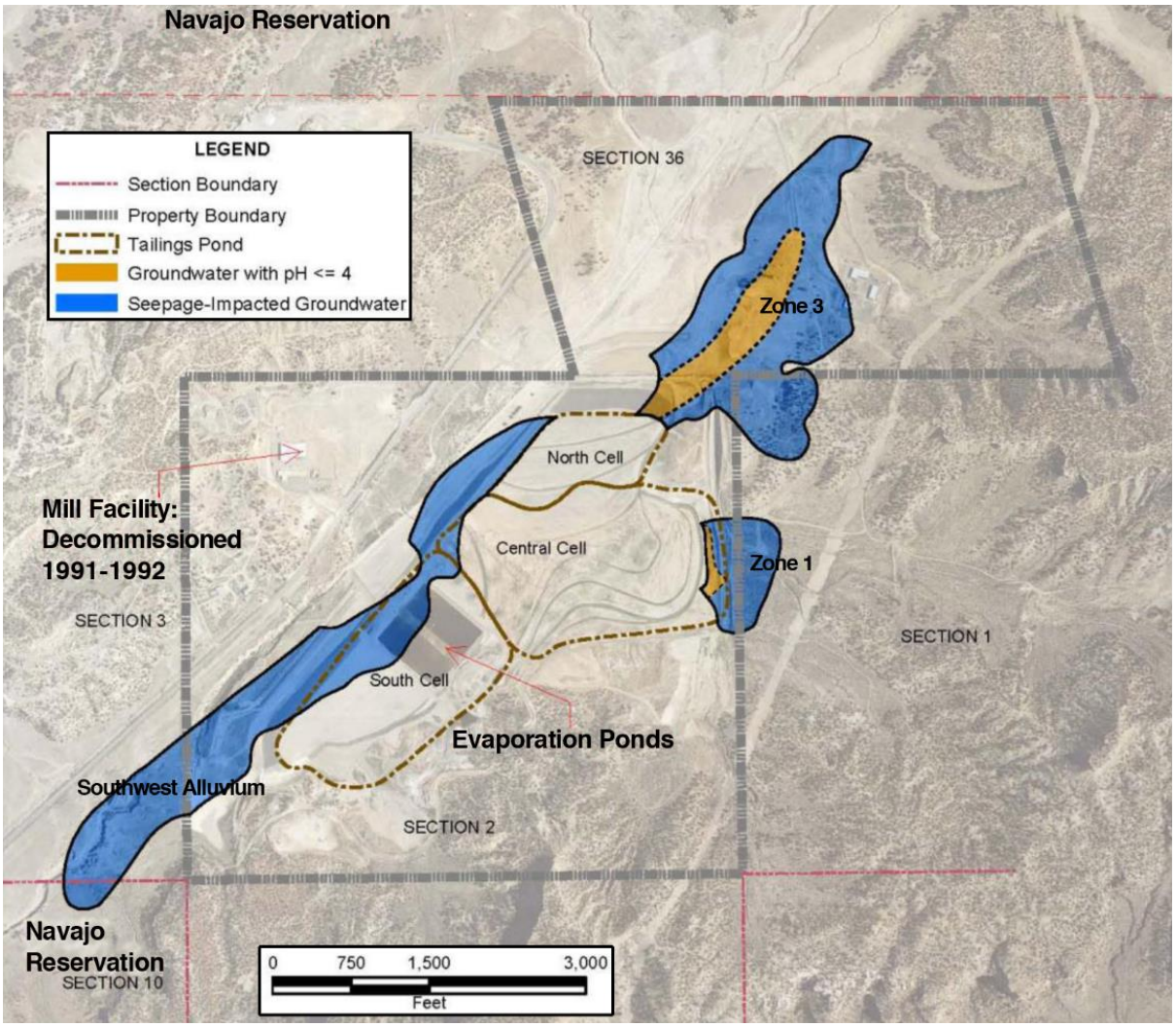

Fig. 5: Seepage-impacted groundwater at the Church Rock Mill Site (USEPA, 2014)

The Tuba City Landfill, AZ:

The Tuba City landfill disposed of unregulated wastes, including tailings from an adjacent uranium mill from the 1940s until 1997. Radionuclides have been measured in groundwater below and down-gradient from the site (USEPA, 2008). There was some debate as to whether elevated radionuclide concentrations were the result of waste disposal or were derived from naturally occurring uranium from the Navajo Sandstone underlying the site or from uranium mined from outside the area, which would have been processed in the mill. A USGS study (Johnson and Wirt, 2009) determined that major and minor elements in leachate and groundwater were more consistent with the Chinle formation, the underlying rock associated with uranium mining operations outside the immediate area. This finding confirmed that it was not naturally occurring uranium that contributed to the observed elevated groundwater concentrations.

Final Disposal (The Grave)

In some ways, the most interesting and challenging part of the story of the uranium lifecycle in the Grand Canyon region is related to its ultimate disposal. Early in the lifecycle, depending on the degree to which it was processed (highly-enriched or low-enriched), most uranium was either destined to be made into a nuclear weapon or used to boil water in a nuclear reactor, respectively. Interestingly, the final resting place for both flavors of uranium is within several miles of each other in a remote part of the Nevada desert, less than 150 miles from the Colorado River. Nearly all of the nuclear weapons detonated by the US were done so at the Nevada Test Site, which has recently been re-named the Nevada National Security Site (NNSS) in southern NV. Here, over 900 nuclear tests took place, both above ground and below ground, releasing nuclear fission products throughout the desert environment there (Cole et al., 1996). Less than 20 miles away lies the Yucca Mountain Nuclear Repository site, where the US government planned to dispose of high-level radioactive waste, mostly derived from nuclear power generation. Both sites must contend with environmental hazards that far exceed human time-scales. During the short time (~60 years) that these sites have been utilized and studied, there have been several unexpected findings that have challenged the scientific understanding of, and ability to contain, the impacts of these activities.

Unexpected findings are all too common in the field of contaminant hydrology, and most result from limited empirical data, contributing to incomplete conceptual models (Bredehoeft, 2005). Limited characterization of subsurface hydrogeology, and incomplete understanding of the physics and chemistry of contaminant fate and transport make sub-surface radioactive waste isolation especially challenging. In the case of Yucca Mountain, the EPA was tasked with the nearly-impossible benchmark of ensuring that waste would be isolated for at least 10,000 years. Notwithstanding the obvious engineering challenge with this target, this exceptional timeframe brings to light some interesting, almost philosophical questions. For example, a task force was put together to determine how to warn humans 10,000 years in the future of the danger buried in Yucca Mountain (Fig. 7). What language do you put the sign in? What kinds of pictures do you include? Certainly there will be some unforeseen ‘surprise’ moments between now and 10,000 years from now that aren’t included in the current conceptual model for Yucca Mountain.

One such case of a ‘surprise’ moment at the NNSS was for transport of plutonium in groundwater. Plutonium readily sorbs with most geologic media, rendering it effectively immobile when released in groundwater. Given that assumption, it was a huge surprise when plutonium was found > 1 mile from a nuclear detonation site at the NNSS. This is because the plutonium sorbed to microscopic colloids, which were readily transported with groundwater, orders of magnitude further than expected (Kersting et al., 1999). Another surprise moment was for Yucca Mountain, when bomb-pulse chlorine-36 was found deep in the subsurface near the waste-disposal location. It was originally thought that deep unsaturated zones in arid environments were hydrologically isolated from meteoric water. Hydrologic isolation is inextricably linked with waste isolation because water is the main transport mechanism for most contaminant. However, this finding forced scientists to re-evaluate the mechanisms for water movement through the unsaturated zone and account for so-called ‘fast pathways’ (Bredehoeft, 2005).

Conclusions

The legacy of the atomic era is an interesting, and in some ways disheartening piece of the history of the Grand Canyon Region and the Colorado River watershed. Recent decisions by the Dept. of Interior to limit new mining claims in the Grand Canyon region have catapulted this issue to the political forefront and have prompted scrutiny of historical uranium mining impacts in the region. Findings from a detailed USGS report indicate that elevated concentrations of dissolved uranium in springs, wells, and streams do occur at times under natural conditions occurring due to proximity to uranium deposits. However, the study also showed that all historical mining sites showed elevated concentrations of dissolved uranium in some form, nearly all of which were above EPA drinking water standards. In addition to impacts at the immediate mine sites, the Grand Canyon region and greater Colorado River have been impacted by uranium milling practices. Poor mill designs and negligent milling practices have contributed to dam failures and leaching of uranium and related contaminants into the Colorado River and adjacent communities. Fortunately, these impacts have generally been local, with little impact on the overall Colorado River water quality. Important questions remain about how uranium-derived nuclear wastes will be safely disposed of given that they will remain unsafe to humans for thousands of years. There is a high likelihood that high-level nuclear waste will be disposed at an underground facility in Yucca Mountain, NV, less than 150 miles from the lower Colorado River. If wastes are disposed there, the Grand Canyon region will have to continue to manage this legacy for many years to come.

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