Local and Expert Knowledge in Experienced Mining Communities:
The Case of a Proposed Uranium Mine in Crownpoint

by

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Abstract

Public access to science is an essential environmental justice component of any mining development. Both limited public access to professional scientific knowledge and little acknowledgment by professionals of the contributions of local knowledge hinder discussion of proposed mines. A proposed uranium mine in Crownpoint, New Mexico, a predominantly Navajo community, presents a case for studying the role of expert and local knowledge in the individual's perception of the risks and benefits associated with the mine. Interviews, supplemented with numerous Nuclear Regulatory Commission documents and other articles of the public record, were used to understand how people developed their personal understanding of the trade-offs of mining uranium in their town. This research reveals that family experiences and personal observations are correlated with individual perception of risk, but the perception of uncertainty is related the group of experts available to the individual. The results suggest that individuals in such communities should have access to a range of experts and that local knowledge and experiences should be taken into account when journalists, industry representatives and government officials translate expert knowledge for public consumption.

Acknowledgments

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How Do Communities Arrive at Perception of Risk: Problem Statement

Knowledge is power.
Francis Bacon

Our power is in our ability to decide.
Buckminster Fuller

The power of accurate observation is commonly called cynicism by those who haven't got it.
George Bernard Shaw

Uranium is about power. It is the main ingredient in the fuel rods used to generate nuclear power that brings electricity to millions and propels aircraft carriers around the world. Enriched uranium and uranium-derived plutonium are used to make world-threatening weapons with the capacity to decimate cities in one blast. Armor penetrating bullets, capable of piercing armored tanks, are made of depleted uranium.

The development of uranium mines invariably invokes power dynamics between mining companies, mining employees, mill operators, reclamation officials, government agencies and residents, whether local or international. Power, in this sense, is partially a function of knowledge. In the United States, this situation is complicated by the location of many uranium ore deposits on Native American land, where cultural and language barriers change both the power dynamics and how knowledge is transferred. The uranium boom of the 1970s was characterized by specific power structures between the uranium mining companies and the Navajo miners. At the time, the Navajo were first switching to wage work from herding, and still establishing a secondary education system. The underground and open pit mines employed hundreds of people. The miners were unaware of the risks associated with underground uranium mining, even though the government and companies knew. This history has meant disastrous consequences for the people of the southwestern US: children with birth defects and thousands of cases of lung cancer.

A combination of new technology and renewed interest in mining has stimulated debate again. Improvements in mining methods, particularly solution mining, have changed the technical concerns and increased the number of economically feasible ore bodies. Changes in the world uranium market increased the price of uranium to decade records. The availability of inexpensive leases complete with technical data has made sites in the Southwest United States attractive to mining companies. These pressures are likely to increase in the future due to increased demand for nuclear power.

The power dynamics of the uranium mining today are different from the 1970s. Many of the communities experienced uranium mining during the massive mining of the 1940s to the 1950s and have not forgotten the problems. New technology has provided new forms of communication between local and regional groups, such as the internet and cell phones. Mainstream American society and local culture has changed dramatically, altering the context of the debate. The role of local and expert knowledge in the dialogue between experienced mining populations and companies as well as the role of different types of knowledge in determining the outcome needs to be further examined in this new dynamic.

The proposed mine in Crownpoint, New Mexico is a contemporary example of the interplay between power, knowledge, culture, and economics. Hydro Resources, Inc began discussions for an *in situ* leach mine within and just outside the town in 1986. Resolution on the topic has yet to occur, despite the advanced level of development. The proposed venture occurs in a large community of Navajo, located in Indian Country[1] in New Mexico. This community can draw on their local history of uranium mining, including prior local solution mining experiments, to make a decision.

By studying the case of Crownpoint, New Mexico's proposed uranium mine, this thesis addresses the following questions: What is the role of local knowledge in public perception of risk of the proposed uranium mine reopening? How do the participants including the mining company, civil society, and individuals in the region categorize the available information? What methods of

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1 The legal term "Indian Country" describes land designated for use of American Indians, including formal and informal reservations, dependent Indian communities, allotments, and other special designations (677 Indian Country Defined 2001)

presentation have a greater impact on risk perception? How does the reputation and credibility of the experts and presenters of information factor into the risk perception of the public? In order to answer these questions, a wide range of stakeholders was interviewed, including residents of Crownpoint, members of active civil society groups, and employees of the company. The scientifically articulated risks include the addition of toxins into groundwater, safety of leaching ponds, long-term reclamation plans, risk of hazardous accidents, air emissions, and other risks.

Several models of public understanding of science have emerged over the last two decades, uncovering many parameters that contribute to common perception of professional scientific knowledge. These models seek to describe the contribution of expert and local knowledge to different facets of individual risk perception. This thesis compares the relative contribution of these parameters to uncover the importance of local and expert knowledge in the Crownpoint community's discussion of a proposed uranium mine. Understanding these connections can facilitate increased access to information for those groups, and improved translation of science into the public discussion.

Background

History of Uranium Mining in Grants Mineral Belt, New Mexico

Uranium mining in the United States began in the southwest. The initial discovery of uranium by John Wade in Arizona in 1918 led to a 1919 Congressional Act opening the Navajo Reservation to mining claims (McLemore 2007). These deposits were eventually used by the Manhattan Project to build the first atomic weapons. Prospecting began in the Grants area in 1950, when a Navajo shepherd, Paddy Martinez, discovered uranium at Haystack Butte (Odell 1999).

The economy of northwestern New Mexico has been heavily shaped by the mining industry. From 1951 to 1980, the Grants uranium district produced more uranium than any other region in the United States (McLemore 2007). Much of the early mining occurred in the Ambrosia, Poison Canyon and West Ranch Areas, as seen in Illustration 1 (Chenoweth and Holen 1980). The intense mining of uranium led to a number of mills to concentrate the ore in the region. Some mine expansion was limited by land and claim acquisition challenges stemming from the diverse land ownership of the area.

The first exploration of the Crownpoint area was facilitated by a Navajo uranium lease sale in 1971 (Chenoweth and Holen 1980). The subsequent discoveries by United Nuclear, Mobil Oil, Pioneer Nuclear, and Continental Oil by 1974 have been developed at very different rates. This is in part related to the different depths of the deposits. The Crownpoint uranium ore bodies were found at depths of 2,000 to 2,500 feet, while the average surface drilling for the region was only 1,024ft (Chenoweth and Holen 1980). The uranium mining methods at the time, including underground mining using tunnels and open pit mining become increasingly expensive at those depths.

Uranium production in the region peaked in 1978 at 9,371 tons of U_3O_8 produced then rapidly deceased in response to quickly falling prices. The decline stemmed from the change in public perception of nuclear power after Three Mile Island, the overproduction of uranium for nuclear power needs and the increase in uranium stockpiles from disarmament, the decreasing quality of New Mexico mines, the unanticipated increases in the costs of reclamation, and the availability of coal as a cheap viable alternative (McLemore 2007). By 1989, all conventional mining, including underground and open pit mining, in the area had ceased.

At present, the price of uranium has increased significantly and the abandoned properties in New Mexico look particularly valuable. Many of the claims are available for low cost, with extensive technical work already completed in a location that lends itself to in-situ mining, a much cheaper alternative to conventional mining (McLemore 2007). This technique is cheaper because the ore is extracted by pumping a solution through the unmoved rock, whereas underground and open pit mining require shifting large quantities of rock and additional processing later. While major oil companies, along with specific uranium and other mining companies, heavily participated in the development of uranium mining claim in the earlier round of mining, the new cycle of mining is characterized by junior mining companies, or uranium specific companies.

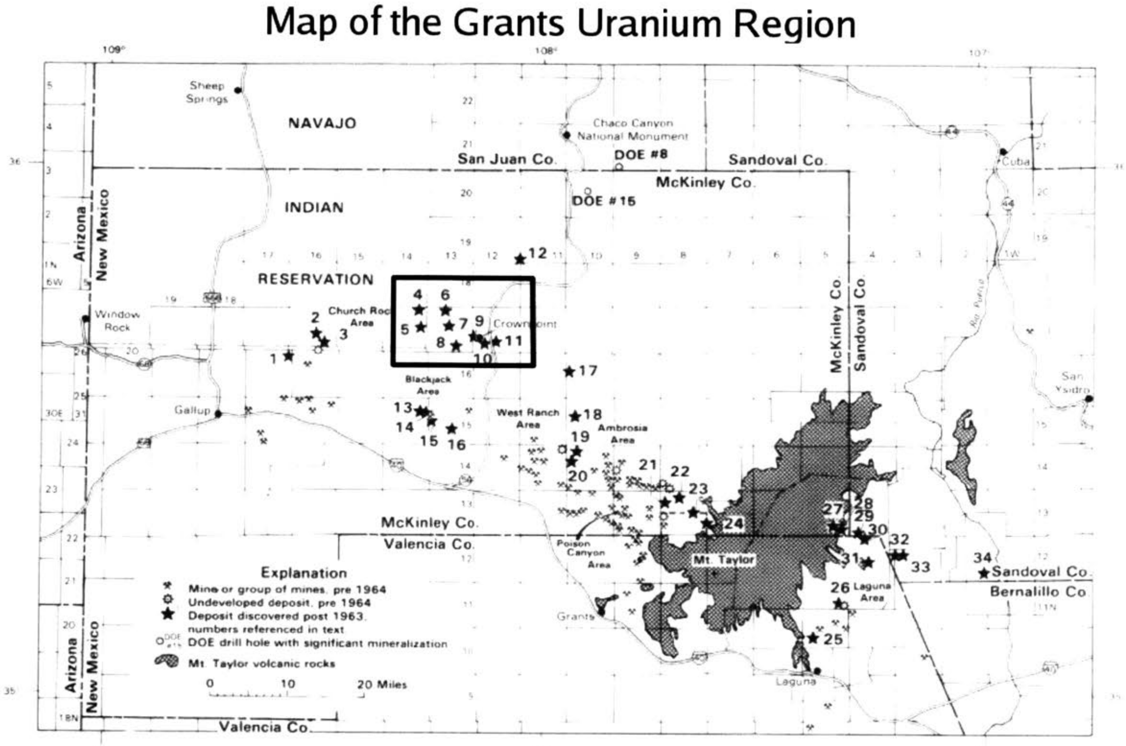

Illustration 1: Map of the Grants Uranium Mining District. The Crownpoint Area is highlighted with a black outline. Note how development before 1963 was mainly in the Ambrosia, Laguna and West Ranch Areas. Image from Chenoweth and Holen (1980).

<u>An Expanding Uranium Market Leads to a Push for New Mines</u>

The price of any mineral commodity drives interest in mineral development and uranium is no exception. The characteristics of the vast uranium deposits of the Grants region, including the grade, depth, and type, determine the ease and cost of extracting the ore. For a given commodities market price, only a portion of the known uranium resources is economically feasible to mine. Because of the large commercial and government inventories and stagnation of nuclear power, the price of uranium oxide dropped to historic lows in the 1990s. Few mines continued to operate, and none opened in the United States. The few companies that pursued licenses were hoping to operate low cost mines using solution mining, rather than expensive underground or open-pit mines. The Crownpoint venture is one such case (they even waited out the lowest dip in the prices in the 1999 to 2001 era when the project became economically unfeasible).

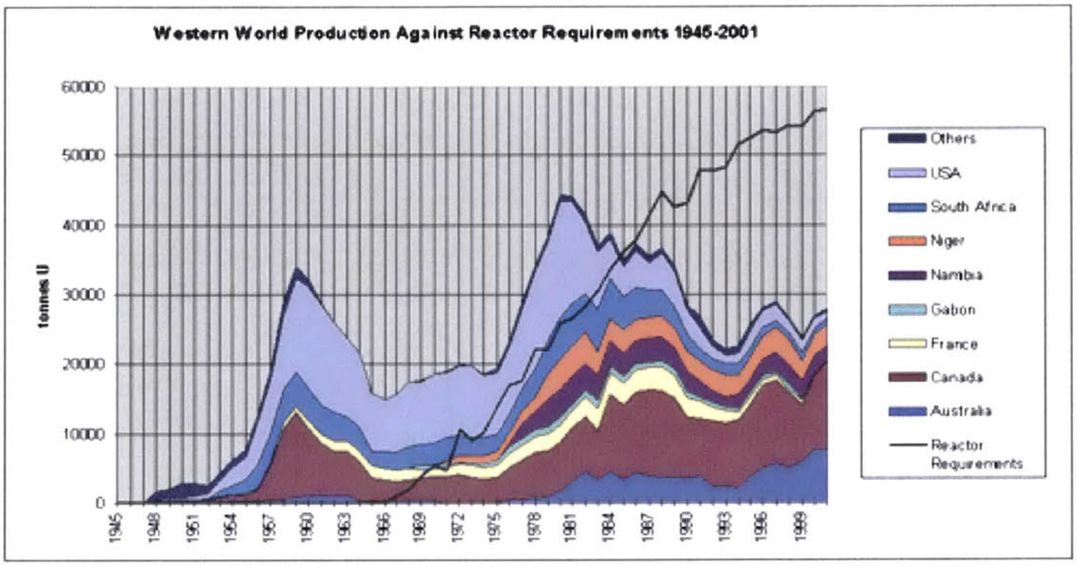

Illustration 2: Production of Uranium Compared to Reactor Needs from 1945-2001. Figure from the World Nuclear Association (Uranium Markets 2006).

During the past five years, the nuclear power industry has received renewed political backing in a number of countries due to concerns over energy dependence and climate change. In October 2006,

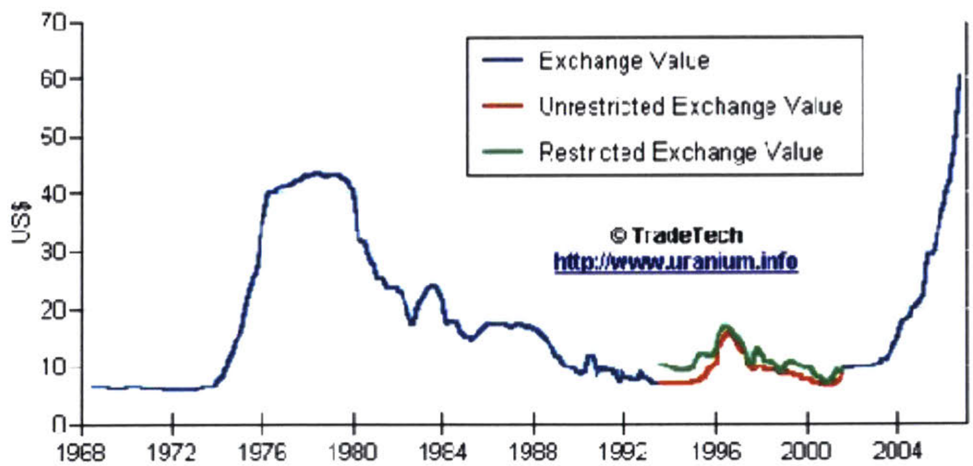

Illustration 3: Uranium prices in $/lb. in three world uranium markets from 1972 to 2005. Note the decrease in the spot price of uranium through the 80s, and the recent increase. Figure from the World Nuclear Association (Uranium Markets 2006).

US petroleum needs were met by importing 64.2% of its monthly consumption, 41.5% of those imports were from OPEC (Data from the EIA, see Appendix III). With the control of most of the world's oil and natural gas reserves in the hands of the political elite of a few nations, leaders in the United States are looking for mechanisms to increase domestic energy security through independence from foreign sources. Looking to the future, the U.S. Energy Information Agency (EIA) estimate energy use in the United States will increase 33.3% from 2004 to 2030, with carbon dioxide emissions increasing 260.95% (Data from EIA reports, see Appendix II). A rising awareness of the potential impact of carbon dioxide and sulfur emissions increases the attractiveness of nuclear power to environmentalists.

With these factors in mind, President Bush has advocated the expansion of the domestic nuclear power supply, including loan incentives, tax credits and insurance for new nuclear power plants. The United States is not the only nation to pursue this strategy. France produced 80% of its electricity though nuclear power in 2001 (Bollaert 2001), compared to the 19.3% of the US electricity grid produced by nuclear power in 2005 (EIA 2006). Japan and Russia have also made nuclear power a large segment of their electricity supply.

The change in national polices with respect to nuclear power has led to speculation of increased future demand in the world uranium market. The main factors in the market are the stockpiles accumulated from the 1940s to the 1980s and the estimated future requirements of nuclear reactors. Following the development of the atomic weapons and nuclear power, the Atomic Energy Commission created a federal procurement program to encourage exploration and mining of uranium ore by setting the price per pound of uranium oxide (U_3O_8), . The uranium boom referred to in the former mining period can be seen in Illustration 2. The US and other governments still have large stockpiles accumulated during over production in the 1950s-1980, comparable in size to the commercial inventories. However, U.S. government officials have made it clear that they do not intend to release large quantities of the federal reserves to meet commercial uranium needs. This news, combined with the potential increase in the number of power plants has sharply increased the spot price of uranium. While a majority of uranium ore from uranium mines and mills is purchased through long term contracts, the commodities market price is both more accessible and more responsive to short-term market projections. One industry analyst, Ux Consulting, placed the April 2007 month-end spot rate of uranium at $113 per pound of U_3O_8, further supporting the trend seen in Illustration 3 (UxC Nuclear Fuel Price Indicators 2007).[2]

Uranium Deposits in the United States

The United States has significant reserves of uranium in Wyoming, New Mexico, Arizona, Colorado, Utah, and Texas. With the price of U_3O_8 over $50 per pound, New Mexico contains 38.3% of the nation's uranium, with the average ore grade around 0.167% U_3O_8 (US Uranium Reserves Estimates 2004). This is higher than the global average ore grade of 0.15%. According to the U.S. Environmental Protection Agency (EPA), "forty percent of the world's uranium reserves occur in strata bound uranium in the Western U.S. (Technical Resource 1995)."

Geology of Church Rock and Crownpoint

The exquisite vistas of the San Juan Basin are the product of millennia of deposition and erosion of sedimentary rocks. Thousands of feet of sandstone, siltstone, mudstone, and shale were deposited over older faults of the Colorado Plateau. The spectacular scenery of mesas and valleys is matched with rich mineral resources, including coal, natural gas and uranium. The highest grade uranium ore bodies tend to be within the Westwater Canyon Member of the Morrison Formation, deposited during the late Jurassic period, although the other members of the Morrison Formation and the Dakota Sandstone contain additional reserves. A detailed stratigraphy of a portion of the Crownpoint stratigraphy can be found in Appendix II.

The Westwater Canyon member is composed of light-red to reddish-orange crossbedded

2 This price has drastically increased in the last months. The week-end price on 8January 2007, was just $72/lb.

sandstone and conglomeratic sandstone with some siltstone. It is sandwiched between the Recapture Member below, and the Brushy Basin Member above the Morrison formation. The latter contains greenish to purplish-gray siltstone and claystone. The Recapture Member is composed of a mix of siltstone and sandstone. The Cow Springs Formation of the San Raphael Group is below the Westwater Canyon Member in parts of the Crownpoint area. This group consists of fine to medium grained, cross-bedded, massive sandstone (Rautman 1980).

The diversity of uranium ore deposits can make determining their origin or predicting their location challenging. Uranium-containing minerals in sandstones can be formed during the deposition of the rock (syngenetic), or as a result of uranium-bearing groundwater after deposition (diagenetic). There is some speculation that the uranium in the Grants Mineral Belt is the result of uranium release from volcanic rocks to the south of the formations. In either case, the aqueous uranyl ion (UO_2^{2+}) is transported by fluids until reaching a reduced environment. The oxidized groundwater also carries other elements, such as vanadium, molybdenum and selenium. The reduced, uranous ion (with valence U^{4+}), can form a variety of minerals. While the most common mineral is coffinite, the Grants Mineral Belt also contains uraninite, andersonite, bayleyite, uranophane, tyuyamunite and carnotite, as described in Table 1 below.

Oxidized Minerals	***Reduced Minerals (U4+)***
Andersonite $Na_2CaUO_2(CO_3)_3 \bullet 6(H_2O)$	Coffinite $U(SiO_4)_{(1-x)}(OH)_{4x}$
Bayleyite $Mg_2UO_2(CO_3)_3 \bullet 18(H_2O)$	Uraninite (UO_2)
Uranophane $Ca(UO_2)_2SiO_3(OH)_2 \bullet 5(H_2O)$	
Tyuyamunite $Ca(UO_2)_2(VO_4)_2 \bullet 5-8(H_2O)$	
Carnotite $K_2(UO_2)_2(VO_4)_2 \bullet 3(H_2O)$	

Table 1: Uranium minerals commonly found in the Grants Mineral Belt

The nature of the reducing environment determines the shape of the ore deposit. A common type of ore deposit is known as a roll-front, named for the shape the formation takes as the reduction-oxidation boundary shifts with time. The dimensions of these bodies can reach several meters in height by hundred of meters in length. In this scenario, the uranium could be naturally reoxidized, transported and deposited repeatedly depending on the chemistry of the groundwater.

Humate uranium deposits are a second major formation common in the Morrison Formation (EPA *Technical* 1995). Humate deposits are long tabular beds of reduced organic matter. These beds can extend for miles, and be only 8ft thick. Because these beds are reducing, the organic matter can act as a trap for uranium, vanadium or other reduction-oxidation sensitive elements in the groundwater (Kesler 1995). The grade of these deposits tends to be higher than roll-front ores. Humate deposits often occur in stacks, with multiple amalgamated beds. These deposits are thought to account for 50% of the total United States uranium production (EPA *Technical* 1995).

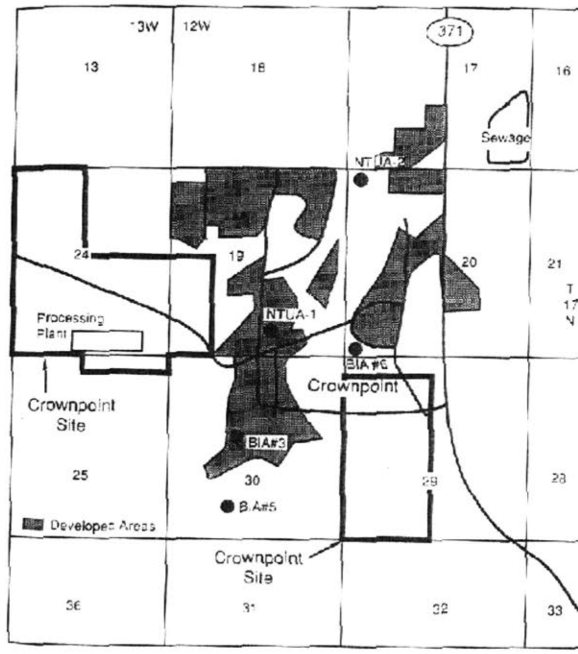

Illustration 4: Location of Crownpoint Sites relative to the developed (residential and business) portions of the town. Note the location of the wells. The closest will be moved by HRI, as a condition of the mining license. Image from the FEIS

Hydro Resources, Inc proposed sites in Crownpoint and Church Rock[3] include 42 million pounds of recoverable uranium ore, with a maximum extraction rate of 3 million pounds per year. The recovery at the ore bodies in Crownpoint is projected to last for 17-19 years in 1996 (FEIS). The ore bodies are located rather close to the town of Crownpoint, as can be seen in Illustration 4.

[3] HRI's proposal includes three different sites, one in Church Rock and two in the Crownpoint vicinity (known as the Crownpoint Unit and Unit 1). The thesis focuses on the two units in the Crownpoint vicinity unless otherwise indicated.

Many of the sandstone layers that contain uranium ores also function as aquifers, including the Dakota Sandstone, the Westwater Canyon member of the Morrison formation and the Cow Springs Sandstone. The town of Crownpoint is heavily dependent on the water from the Westwater Canyon Member, a classic artesian aquifer. Water is currently produced via 5 public wells and several private ones, serving over 2,500 people. The concentrations of various chemical species in the water are contained in Tables 2 and 3. This water is of higher quality than water from the Dakota Sandstone, but both meet drinking water standards (FEIS).

Chemistry and Mechanics of Solution Mining

Solution mining is argued to be the cheapest and least environmentally degrading form of uranium mining. This method avoids the high construction and restoration costs of open-pit and underground mining. One of the main risks to miners, exposure to airborne uranium in mine dust, is eliminated. Finally, in situ mining does not permanently change the landscape. This is the only economically feasible method at low uranium market prices. Higher prices would allow economical access to high grade ores in deposits not conducive to water flow.

The magic of in situ mining is that uranium is extracted from underground ore deposits without mining the host rock. The overall process involves pumping an oxidized fluid into the ore-bearing sandstones, which puts the uranium into solution. The uranium enriched solution is then pumped to the surface where the uranium and other elements are extracted at a processing facility. After a certain percentage of the ore has been extracted, the mine is restored to its original condition by collecting the remaining soluble ions and putting reductants into the groundwater.

To draw the uranium into solution, gaseous oxygen and sodium-bicarbonate are added to water

Chemical Species	***Background (mg/L)***	***Mean Water Quality (mg/L)***	***EPA (and NNEPA) drinking water standard***	***Concentrations in Mining Solution (mg/L)***
Calcium	2.0	2.68		100-350
Magnesium	0.1	0.44		10-50
Sodium	110	120.3		500-1600
Potassium	3	10.58		0-500
Carbonate	27	26.42		0-500
Bicarbonate	195	201.22		800-1500
Sulfate	35	54.9	250	100-1200
Chloride	3	10.9	250	250-1800
Nitrate	0.04	0.05	10.0	<0.01-2
Fluoride	0.03	0.35	4.0 or 2.0	0.05-1
Silica	17	16.2		25-50
TDS	320	367.8	500	1500-5500
Uranium	0.005	0.001	0.03	50-250
Radium-226	0.7	65.85 (pCi/L)	5.0 pCi/L	>100
Conductivity	415	700.5		2500-7500
pH	9.0	9.0	6.5-8.5	7.0-6.9

Table 2: Levels of Chemical Species in the aquifer prior to mining. From FEIS Table 3.13 and Table 4.5, with EPA Drinking Water Standards updated.

Chemical Species	***Mean Water Quality (mg/L)***	***Maximum (mg/L)***	***Minimum (mg/L)***	***EPA (and NNEPA) drinking water standard***
Arsenic	0.0	0.001	0.0	0.01
Barium	0.05	1.0	0.0	0.05 (2)
Cadmium	0.0	0.0008	0.0	0.005
Copper	0.0	0.92	0.0	1.3
Iron	0.03	0.1	0.0	0.3
Lead	0.0	0.013	0.0	0.015
Manganese	0.0	0.029	0.0	0.05
Molybdenum	0.0	0.02	0.0	
Zinc	0.0	0.03	0.0	5.0
Boron	0.06	0.11	0.0	
Ammonia	0.03	0.31		

Table 3: Levels of Chemical Species in the water from the Westwater Canyon aquifer prior to mining. From FEIS Table 3.13, with EPA Drinking Water Standards updated. Chromium, Mercury, Nickel, Selenium, Silver and Vanadium were undetected.

on site, and pumped in the ground. The uranium is oxidized by the oxygen and becomes aqueous:

$$UO_2 + \frac{1}{2}O_2 \leftrightarrow UO_3 \quad \textit{Equation 1}$$

$$UO_3 + CO_3^{2-} + 2HCO_3^{-} \leftrightarrow UO_2(CO_3)_3^{4-} + H_2O \quad \textit{Equation 2}$$

The aqueous species then forms a more stable compound with the carbonate. The solubility is greatly magnified by the presence of dissolved carbonate ions (CO_3^{-2}), which form a series of uranyl tricarbonate complexes (Davis 2007). Other elements are also dissolved during this process.

The enriched solution is pumped to a processing facility, where the mixture passes through ion exchange resin to isolate the uranium. The barren water is injected with oxygen and carbonate, and re-injected into the mine field. The resin beads, which have a capacity of 13% uranium by weight, are then removed and separately stripped of uranium with chlorine ions from salt (NaCl) (Gallup *Processing* 1994). When the resin is returned to the flow, the chlorine ions enter solution and are pumped into the ore body. The uranium is precipitated with ammonium (NH_4^+), and dried at a central processing plant in Crownpoint to create yellowcake – the uranium dioxide that is sent away to be further concentrated and refined.

A key component of controlling the underground water flow is the maintenance of a bleed of water from the cycle – 1% of the flow is constantly siphoned off to create a negative pressure gradient in the groundwater around the mine field. After the dissolved uranium is extracted, the extra fluid is put into large lined settling ponds to allow minerals to precipitate, and then the remaining solution is applied to the land to evaporate. In the case of Crownpoint, 54,000 gallons per day (19.44 million gallons per year) will be siphoned into lined lagoons for evaporation (Public Notice 9 Jul 1993). The pressure gradient causes groundwater to flow into the well field, creating a safeguard against the enriched solution remaining in the aquifer or contaminating other aquifers.

The groundwater flow is also controlled by the well field. The pumping rates of each well are individually set to balance the water flow and prevent uranium bearing fluids from escaping. The spacing between production and injection wells can be anywhere from 20 to 200 feet (EPA *Technical* 1995). These sites are surrounded by monitoring wells, spaced approximately 400 feet apart, and checked every 2 weeks. Prior to mining, the company is required to establish indicators and quantities for each well field, based on the geologic characteristics of the well field (Mudd 1998). Chlorine ions are frequently used as an indicator, because they are pumped into the ore body as a result of processing, as described above.

Once all economically feasible uranium has been extracted from the mine (in the case of Crownpoint, about twenty years), the well field must be restored to its original state. The initial characteristics of the aquifer are carefully measured before wells are drilled. The company must restore the field to this state in the end, or to standards set by the national and state governments as specified in the mining license (Mudd 1998). Because the Westwater Canyon member acts as a drinking water source for the residents of Crownpoint, the company must reclaim the aquifer to Navajo Nation and national water standards.

There are a number of methods for restoring the quality of the groundwater, each of which has different implications for long-term water availability in the aquifer. Each process involves replacing contaminated water (water with concentrations of uranium and other elements too high for consumption) with water that meets baseline standards. During a groundwater sweep, uncontaminated flow is induced into the area, as contaminated water is extracted and treated. Two or more pore volumes are generally required to completely restore the groundwater, resulting in much less groundwater compared to other methods. Two other methods are the forward or reverse recirculation, where water is cycled through the existing wellheads, treated and re-injected. These methods conserve groundwater, but do not allow for the removal of escaped chemical bearing solution. Finally, there is the directional groundwater sweep, where contaminated water is pumped from wells in the field, treated, and injected just beyond the original well field. This method can progress across the mine field, rather than cleaning the entire field simultaneously. Chemical reductants can also be added to the flow to alter the oxidation state of the groundwater. The Final Environmental Impact Statement (FEIS) suggests 4-9 pore volumes would be required to restore the groundwater to pre-mining conditions, or to drinking water standards in Crownpoint.

Despite these techniques, restoring groundwater quality can be challenging depending on the geochemistry and hydrology of the area. Mobil Oil ran a test solution mine in the Crownpoint vicinity during the 1980s. The company was unable to restore the concentrations of 19 out of 29 pre-selected contaminates in this small scale well field, and molybdenum exceeded national water standards. The restoration challenges pose a potential long-term threat to groundwater quality.

Failure to completely restore the mine can manifest in other ways. Excursions, or contaminated water traversing the world outside the well field, represent a danger to the groundwater quality. Monitoring wells are designed to discover horizontal excursions in the same layer, as pumping is expected to change the groundwater flow in the vicinity. At Crownpoint, concerns with horizontal excursions are based on two modeling parameters. The first is the homogeneity of the sandstone which contains the deposit. While classic roll-fronts can be crudely modeled as homogeneous, humate uranium deposits can be notoriously variable in composition. The second debate is in the existence of fast pathways along paleo-channels and streams. Composed of coarser grains and with a higher permeability, these zones could quickly transport ions between monitoring stations. The modeling debate was brought to the NRC court by grassroots and regional opposition groups that wanted the license changed to have more monitoring wells. The NRC agreed with the company: the deposit can be modeled as homogeneous, and the industry 400 foot standard between monitoring stations stands.

Vertical excursions are far harder to detect. The geology of the area seems predisposed to prevent vertical excursions, with impermeable layers above and a higher hydraulic head aquifer below.

However, vertical excursions are frequently associated with poorly capped old borehole shafts, a phenomenon that riddles the landscape of the Grants Mineral Belt. This could allow leakage into the lower pressure aquifers above the ore zone. As the aquifer in which mining takes place is the drinking water source, there is not much interest in the fate of these other layers.

Potential Environmental and Health Impacts

The biggest threats to human health associated with in-situ mining of uranium are accidental exposure to uranium and other metals, acids, ammonium and salts associated with the process of pumping enriched waters and transporting refined uranium ore. Acute exposure is a concern during the processing and transportation of the yellowcake. The roads of McKinley County have some of the highest accident rates in the country. The resins will be transported regularly to the central processing facility in Crownpoint from the two Crownpoint fields, and from the operations in Church Rock. The yellowcake must then be transported to milling facilities. Acute and chronic exposure could result from an excursion, if the solution reaches groundwater used for human or livestock consumption or irrigation. If restoration is not completed properly, contaminants could reach groundwater consumed for human use after a delay of decades to hundreds of years, leading to problems in the future.

The predominant chemical danger is exposure to high concentrations of the aqueous uranyl (UO_2^{2+}) ions. Soluble uranium presents chemical and radiological risks. Plants absorb the uranium onto their roots, but not necessarily into the body of the plant and livestock usually quickly eliminate uranium like humans do – in feces and urine (CDC 2006). However, if raised in conditions with high exposure to uranium, ingestion of contaminated crops and animals could have negative health impacts. High doses of uranium (50-150mg) can lead to acute kidney failure. These doses are similar in concentration to the projections for uranium in the solution (50-250 mg/L), but would be noticed by the consumer. Smaller doses (25-40mg) lead to kidney damage, which can be detected through protein and dead cells in the urine. The body can heal the kidney damage given several weeks without exposure to uranium. Very high doses of uranium have led to birth defects in lab animals[4], implying an increased rate of birth defects if pregnant women are exposed to high doses (CDC *Toxicological* 2006). The chronic ingestion of uranium is less understood. A 1998 study concluded that the subclinical toxicity of chronic low level ingestion of uranium (levels of less than 1 microgram per liter of water) could lead to irreversible renal injury (Zamora 1998).[5]

The impact of uranium on kidneys may be of particular concern in Crownpoint. Navajo have been found to be at increased risk for end-stage renal disease (ESRD) in a study done by Hochman, Watt, Reid and O'Brien (2007). While much of this risk is attributable to the higher rates of diabetes amongst the Navajo, the authors note that the prevalence of non-diabetic ESRD is still two times that of the general U.S. population. Some scientists fear that chronic exposure to increased levels of uranium could aggravate the problem (Fogarty 2003).

The radiological risks associated with inhaling or ingesting natural or depleted uranium are remarkably low. Uranium mainly emits alpha particles, which are easily blocked by human skin. Although solution mining eliminates the uranium dust so prevalent in the old underground and open pit mines, the risk of ingesting uranium remains a concern. A small portion of the uranium that enters the blood following digestion can remain in kidneys and bones for years. Thus, one study found increased risk of kidney and urinary tract cancers at homes dependent on well water with high amounts of uranium (Kurttio 2006). According to the CDC, natural or depleted uranium rarely leads to cancer, because the rate at which the particles decay is so much longer than the residency in the human body. For cost-benefit purposes, one committee estimated that roughly 1-2 of a million people will develop sarcoma, a bone cancer, after 70 years of ingestion of 2 micrograms of natural uranium per day. It is

4 The smallest dose this appears to occur at includes oral ingestion of 3 mg per kilogram of body mass per day in rats, which would translate into high doses for humans. However, the relationship between amount consumed and effect are unclear.

5 This study also discovered that the damage is located in the proximal tubule of the nephron (kidney). This is where water is reabsorbed into the capillaries.

possible that uranium dust can aggravate cancer risk, for example, miners exposed to carnonite dust containing uranium have increased risk of lung cancer, but those exposed to pure uranium dust do not (CDC *Toxicological* 2006).

The dangers are not limited to uranium. The lung cancers of the open pit and underground miners have been attributed to radon and its daughter products, particularly amongst Navajo who smoked (CDC *Toxicology* 2006). Similarly, other chemical species which could be released by ISL present toxicological implications for human health. During a pilot test in the Crownpoint vicinity in the 1980s, Mobil Oil was unable to return aluminum, arsenic, molybdenum, pH, sulfate and uranium to baseline even after 16 pore volumes of ground sweeping (Intervenor's, 2005). Other sources state this pilot test was "exceptionally 'clean' but with molybdenum byproduct" (Davis 2007). The applicability of this information to the Crownpoint units in this case is limited, as HRI claims the geochemistry at its sites shows little to no molybdenum (FEIS). Vanadium is commonly associated with uranium in many roll-front deposits, but this appears to not be the case in the Grants Mineral Belt (Memoir 38 1980). Selenium is also of interest, although has not been detected in the Crownpoint groundwater (See Table 3 above).

History of Crownpoint

Over 20 years of debate on the proposed Crownpoint Mine has honed public opinion. Opportunities for discussion were found in the process for receiving a license for the mine and in adjudication between various civil society groups and the company. The dialogue focused on the ability of the company to prevent accidental and gradual releases of uranium and other toxic chemicals, the financial capacity of the company to complete reclamation, the quality the water must be restored to, and the motives of each participant. Active groups include three different levels of government, corporations, and civil society organizations. Each aspect of the conflict highlights the role of science in the development of public understanding and perception of risk.

Early steps in the licensing process went smoothly for the small corporation, Hydro Resources, Inc (HRI). As the mine is located in the Eastern Navajo Agency[6], indigenous landowners of the proposed pump field were offered $367,000 per initial lease between 1988 and 1992. By 1996, the final environmental impact statement was well underway. HRI even had the support of New Mexico's Senator Domenici. Members of the community voiced concerns about the risk of contamination of the aquifer, but the company brushed them off as caused by "ignorance and jealousy" (Shuey, 1996). Following all relevant procedures, the Nuclear Regulatory Commission (NRC) extended a license for the Crownpoint and Church Rock mines to HRI in 1998.

By the conclusion of this process, several civil society groups had become established voices in the debate. As early as 1988, some residents of Crownpoint organized their voices of protest in an group called Diné Citizens Against Ruining the Environment (CARE)[7]. Some of the residents of Crownpoint formed the Eastern Navajo Diné Against Uranium Mining (ENDAUM), to protest the mining venture based on technical health and safety arguments. This group worked closely with Southwest Research and Information Center (SRIC), a regional non-profit based in Albuquerque. SRIC has been heavily involved in providing resources to indigenous communities with mines in the last decade. In contrast, Navajo who would receive lease payments formed the Eastern Navajo Allottee Association to protect their right to develop minerals on their land (Helms 2005).

ENDAUM and SRIC hired the New Mexico Environmental Law Center (NMELC), a non-profit working for environmental justice, to pursue legal barriers to mining. NMELC has brought several cases opposing the license to the NRC judges who arbitrate such disputes. The non-profit succeeded in putting a hold on HRI's ability to mine in Crownpoint within a year of the license being issued. The

6 The Eastern Navajo Agency is not part of the reservation, but is classified as "Indian Country" by the federal government. Those living on this land are considered "Navajo Allottees" and they have the power to do as they wish with their land, within the laws of the Navajo Nation.

7 Diné means Navajo.

first major case focused on the environmental health and safety concerns associated with in-situ leach mining. These concerns include aquifer contamination with uranium, impact of other toxic metals, worker safety, reclamation feasibility, tailings dust and more. Technical modeling arguments were made by each side. The NRC judge decided in favor of the company in 1999.

The second major case pointed out further safety arguments, and asked for financial assurance that reclamation would occur. The judge upheld the latter request in 2000. In a 2005 opinion, the NRC justice reduced the legal amount of uranium in the groundwater of Crownpoint at the conclusion of mining from 0.44 mg/L to 0.03 mg/L in 2005. In 2006, the NRC rejected the air emissions and tailings arguments of those opposed to the mine.

ENDAUM and SRIC succeeded in greatly increasing access to scientific information in the community (and for themselves) through the placement of a NRC local document repository (LDR) in Crownpoint. Prior to it's arrival, interested members of Crownpoint could access the document's in HRI's private Crownpoint facility. For public access, interested parties had to visit the national repository in Washington, D.C. or pay twenty cents per page for a copy. The information control issues connected with public documents being located in a private facility convinced the NRC judge to require the LDR. It is not yet understood how large an impact this had on the local debate.

The company was also making progress during this period. In 1999, the New Mexico Water Quality Control Commission approved the use of groundwater for mining in Crownpoint. In 2000, the Navajo Nation lifted its ban on in-situ leach mining (this had applied only to reservation lands, and thus was not directly applicable to HRI), further encouraging the company. By 2002, the HRI had issued another restoration financial assurance plan. At the same time, the EPA was investigating who had jurisdiction over drinking water standards in the area – the EPA, or Navajo Nation. This jurisdiction questions would impact the water quality standards the company is held to.

The Navajo Nation banned all uranium mining and milling on both the reservation and on agency lands[8] in the Diné Natural Resources Protection Act of 2005. This decision came after many Navajo nation hearings with different local experts. However, at the Council meeting, concerns over the past misdeeds of mining companies and the continued lack of adequate compensation for mining-related injuries during the 1950s-1980s prevailed over the hopes for further income and financial resources to the area. In is unclear if the jurisdiction of this legislation over Indian County will be accepted in a court of law; the Navajo Nation may have to compensate the owners for the mineral rights. It is also possible that HRI can convince the people of Navajo Nation that their mining proposal is safe or distinct from the previous uranium mines.

To that end, HRI filed an appeal of a EPA decision that Church Rock, a second property, should be classified as Indian Country. If the designation remains, HRI would need to obtain an underground injection control permit from the EPA and test the Navajo uranium mining ban. Mining the Church Rock property would allow the company to develop one property, prove its ability to restore ISL operations, and convince Crownpoint residents of the safety and benefits of uranium solution mining.

Throughout the debate, the value of different types of science is implicitly analyzed by participants. Comments about motivation and expertise undermine the credibility of the opponent's science. There is concern that the technical models created by HRI are not applicable to the Crownpoint hydrology, a direct example of a perceived tension between expert science and local realities. Finally, the history of mining in the area has led to little trust of companies. This points to the crux of the issue: what science do the people in this community trust?

Modeling Public Perception of Risk

Several approaches can be taken to understand the development of risk perception in a uranium mining community. A body of literature concerning the "public understanding of science" has emerged

8 This includes the Eastern Navajo Agency, where Crownpoint is located.

from the field of sociology. As part of this set of ideas, authors explore the way in which scientific literacy impacts the public's use of science in representative democracy decision making processes. In contrast, risk perception models emphasize the weightings and credibility of various forms of knowledge. The relevant aspects of the models will be explored below, combined with an understanding of the Navajo context and forged into an open model to aid in understanding the discussion in Crownpoint, New Mexico

Models of Public Understanding of Science

The first major model in the field is based on the assumption that the lack of widespread scientific literacy led to unease, mistrust and even hostility to science (Sturgis and Allum 2004). The model is term the "deficit model" or the "traditional model." The concept of scientific literacy continues to be refined. Originally focused on the content of public knowledge, Miller extended the definition to include both an understanding of the institutional process and scientific method of generating expert knowledge and an understanding of the impact of science. This expansion was validated in an analysis by Tytler, Duggan and Golt (2001) by looking at key information in one town's attempt to change industry behavior. For example, in a case of air quality modeling of a city, understanding the method scientists use, the culture of the air pollution modelers, the culture of the city institutions who would have access to the information, and the potential impact of the scientific results are necessary to empower a participant to affect the actual outcome. This extended concept of scientific literacy is important in understanding the use of knowledge.

Under the traditional model, the world is divided into two conflicting groups – the experts who debate issues, and the anxious public. In such a case, the more formal science a person knows, the increased likelihood of a positive attitude toward expert science. While Sturgis and Allum (2004) are quick to point out this model is well supported by empirical evidence (surveys) connecting science knowledge and attitude in policy debates, this model does not provide a role for local and expert knowledge. It simply underscores the importance of scientific literacy.

The specific instruments used to measure the model reflect the author's assumptions. For the deficit model, Sturgis and Allum (2004) simply look for correlations in degree of general attitude toward science (whether it is useful and accurate), and degree of science knowledge. This model is limited to the pursuit of education, rather than empowerment of the public.

In the spirit of the extended definition of scientific literacy, scholars have created the "contextualist model." This approach, touted by Wynne, takes into account the process of knowledge generation and the institutional embedding of formal or informal knowledge (Sturgis 2004). Institutional embedding is the idea that knowledge should be seen in the context of the existing social structure of the organization. Those structures can adopt knowledge into their culture. However, the culture of a place impacts the science they choose to use, and how they react to new information. Several authors have explored combinations of the premise of these models (Sturgis and Allum 2004, Tytler, Duggan and Golt 2001). Of special interest is the way each model casts the roles of the participants, and the parameters used to assess the science dialogue.

The contextualist model suggests a different set of roles: professionals recommend generalized solutions, while local people advocate changes to those solutions based on local context and knowledge of human behavior and institutions. In this case, two different types of knowledge are produced by two different sets of participants with very different ramifications. Furthermore, this model suggests that the public should have a voice in the underlying normative assumptions that formal experts use in their analyses. This is a basic local – expert knowledge concept that divides expertise based on individual day-to-day activities from specialized scientific knowledge. The idea that a local community may have a valid concern or point about regional behavior has proved a powerful shift in thinking.

There are more advanced concepts for framing participants and their roles. Many authors recognize the existence of a variety of publics with different needs and interpretations such as Irwin &

Wynne's 1992 book or Davison, Barns & Schibeci's 1997 study (Stugis 2004). Tytler, Duggan and Golt (2001) include decision-makers, policy leaders, the attentive public, interested public and the non-attentive public in their framework. Alternatively, a dialogue could be marked by an oppositional group with counter-expertise, rather than a loose association of members of the public.

In the context of the United States, the participants need to be decoupled from the content of their argument. Stakeholders can be characterized in the following broad boxes: government agencies (at the federal, state and local levels), the corporation, organized civil society groups (for or against a proposal or activities), the media, the local and regional interested public, and the non-attentive public. Formal scientists can be hired by any of the organized groups, agencies or companies. Frequently, they take the form of a consulting company, or occasionally a non-profit. At the same time, any of the groups can use local knowledge (provided the knowledge is accessible, the group is nimble in focus and awareness). The bias in the selection of knowledge for use by each of the stakeholders reflects the culture of those organizations. As each institution chooses a stance on the risk of an activity, the public pulls information from these organizations, combines it with their own prior knowledge and determines their own perception of risk.

The selection of measurable parameters for the contextual model is complicated. Each suggestion finds measures of institutional or local knowledge, often making leaps of logic (Sturgis and Allum 2004). Baurer and others recommend splitting institutional knowledge into the autonomy of scientists and the way in which institutions function. Selecting the parameters requires an ability to identify activities with an overlooked impact on the real outcome. A framework by Funtowicz and Ravetz suggests the type of knowledge used is colored by two parameters: confidence and knowledge of the decision making system, and magnitude of the consequences. In this context, the public can operate as a form of peer review, giving the experts their input on the local context of technological or methodological concerns, and becoming the expert when it comes to epistemological concerns

(Yearley 2000).

Alternatively, a more complex model offered by Wynne focuses on 4 system parameters: risk, uncertainty, ignorance and in-determinacy. Wynne suggests risk and uncertainty are both obtained from formal studies, and that knowledge of topics that cannot be measured (ignorance), or of topics that are not determinable (in-determinacy) are found by the public placing trust in one study or another, or in the local knowledge. Building on this, local knowledge can impact both risk and uncertainty studies, but local knowledge is expert at information formal scientists cannot measure or cannot know to try to measure. After all, such a decision is the realm of public policy, and the public is the one accepting the risks.

Further parameters are suggested by Tytler, Duggan and Golt (2001). These authors highlight the role of translation in public science, and the large number of channels of information dispersion, and the importance of "dispersal of ownership of science." The ability of this democratic approach to science in evoke a more realistic view of science has been documented by several scholars such as Irwin, Dale and Smith (Tytler 2001).

Relevant Parameters for Crownpoint
Confidence in and knowledge of the decision making process
Magnitude of the consequences
Risk
Uncertainty
Immeasurable factors (ignorance)
Unknowable (indeterminacy)
Translation from expert to public science
Channels of information dispersion

Table 4: List of the relevant parameters to measure awareness of science for the debate in Crownpoint, New Mexico as derived from the models of public understanding of science.

Public Risk Perception Theory

Another key field for approaching public decision making is the field of risk perception and communication. This arena focuses on analysis of the methods of communication and establishing credibility. Like the field of the public understanding of science, this field has its traditional and emerging models. The traditional model, termed conventional risk communication, looks at the intentional transfer of information in public settings from experts to the public. This is a limited subset of the risk communication work in general.

In contrast, symbolic risk communication looks at public or private transfers of information, including unintended messages. Unintended messages could arise from the institutional agenda, the location and other such variables. An extension of this concept is the idea that risk events interact with other process to impact individual risk perceptions. The sharing of these risk events is controlled by "amplification stations" - information bottlenecks, where knowledge input, processing and dissemination occur on an individual basis. The analog for social groups is termed a "social station of amplification" (McComas 2003). As a result of these frameworks, authors feel that to understand technological risk perception, the researcher must include the stakeholder narrative in their understanding (Gregory and Satterfield 2002).

A separate framework is used to analyze credibility. Constructivists argue that credibility depends on context, while others use a more static model. The situation by situation framework allows individuals to analyze a speaker's credibility by a different weighting of criteria each time. These shifts in credibility are integral to understanding why a group of people may change their opinion on an issue, or accept one set of knowledge and not another. This credibility is tied to both the reputation the disseminating organization has, and on the intended and unintended messages in the presentation or distribution of the science to the public.

Risk perception scholars commonly study public meetings, a tool often employed by government agencies. Researchers use public notes, attendance rates, and responses to questions of credibility and other such variables to analyze the relative effectiveness of the programs (McComas 2003). These concepts will be used to look at perception in Crownpoint

The integrated models mentioned above will be used as a framework for the analysis. Maintaining awareness of the variety of publics in existence while keeping track of the type of knowledge they are generating or processing will provide a frame for the flow of technological information. Using a stakeholder narrative, and the concepts of symbolic risk communication and the constructivist approach to credibility, the analysis will include what knowledge the local public had access to, what knowledge it wish it had access to, and how the public reached it's decision. To thoroughly understand these knowledge flows, they must be put in the context of the Navajo culture.

Navajo Culture and Uranium Mining

The community's discussion of the uranium mine must be placed in the context of broader Navajo culture. The major themes discussed by scholars of the Navajo way of life will be highlighted, along with those aspects that are particularly relevant to this case. These include adaptation, sovereignty, Navajo philosophy and the Navajo economic narrative about uranium mining.

Two key themes of the Navajo way of life are adaptation and sovereignty. Anthropologists and historians highlight the ability of the Navajo to selectively incorporate new ideas without discarding Navajo identity, and to apply the Navajo culture in new contexts (Downs 1972, Iverson 2002). One example presented by Iverson concerns a young woman who aspired to become a pilot, but feared the implications of entering the bird world. After consulting with a singer (a Navajo elder commonly known as a "medicine man"), she brings a beaded eagle feather with her on flights and uses it to mark her flight log (Iverson 2002). The feather allows the bird people to recognize her and her place with the Navajo people.

On a more societal scale, the base of the Navajo economy has shifted from raising sheep and goats, to cattle, to wage work, with the Navajo adapting to each new adjustment (Downs 1972). English has become more common, despite many attempts to preserve Navajo as a bastion of the culture. An example of this adaptation is progress was the varying faith in technology exhibited during the interviews, such as in the use of email and cellular phones. The young to middle aged cohorts are more likely to use this technology. Certainly this phenomenon and its like are found in other cultures, but placed in the context of uranium mining, and the preservation of a way of life, technology takes on a more important role as a method for accessing information. Highlighting this ability of the Navajo to endure and adapt seems to partially be a reaction to the fears that the Navajo way of life will disappear.

While adaptation remains a major component, the Navajo culture also emphasizes expansion and sovereignty as mechanisms to maintain a distinct culture (this idea is supported by legal scholars like Krakoff 2005). The Navajo were one of the few American Indian groups able to stay in their homeland (after the traumatic forced migration known as the Long Walk followed by several years of exile at Fort Sumner from approximately 1964 to 1968) (Iverson 2002). The reservation was actually expanded over the years, as the then named Navajo Tribe fended off attempts to move the entire reservation to allotments. During the early twentieth century, the United States government shifted much of "Indian Country" from the formal reservations, where the land is controlled by the tribe as a whole through a tribal government or the Bureau of Indian Affairs (BIA), to allotments, where control over a small portion of land was given to specific American Indian individuals (or families), although this land is still held in trust by the BIA. In the case of the Navajo, the tribal land was not divided, but additional land just off the reservation was divided into allotments. The history of the trust system though which the United States federal government manages the reservation and allottee lands – a history of mismanagement – contributes to the current push for increased sovereignty.

Since the Navajo finally achieved citizenship status in 1924, the Navajo Nation has worked diligently establish sovereignty in the region. The 1950s saw the federal courts reaffirm the right of the Navajo to govern themselves in Native American Church v. Navajo Tribal Council, and Williams v. Lee. The lack of state jurisdiction over the Navajo reservation was established in McClanahan v. Arizona State Tax Commission in the early 1970s (Iverson 2002). The sovereignty extends to all people on the reservations and the allotments off of the formal reservation (Hale 1998). Sectors that are not yet developed within the personnel of the Diné government are overseen by various federal agencies. One example is the interplay between the Navajo Nation Environmental Protection Agency and the U.S. Environmental Protection Agency, the latter of which is called in for situations where the NNEPA does not have the in-house technical expertise. The Diné continue to be wary of losing any of this hard earned sovereignty.

HRI's proposal impacted the battle for sovereignty, despite the company's repeated statements that they would work with any and all appropriate agencies. One of the earliest signs of trouble was the debate over which agency was responsible for regulating the groundwater and the resident's drinking water. After the New Mexico Health and Environment Department tried to establish jurisdiction, the Navajo Tribal Utility Authority and the Southwest Research and Information Center sent letters to the NRC, the BIA and other relevant agencies calling for involvement of EPA Region IX. In the end, the US EPA oversaw the drinking water requirements of the proposal instead of the Navajo Nation Environmental Protection Agency (there is no evidence of legal contestation of this point until 2006). Interestingly, the EPA office that claimed jurisdiction, based in San Francisco, was seen as having little technical capacity to analyze the ISL process, according to records from HRI. The regulators appear to have undergone their own education process to be able to analyze the technical documents. The only public role HRI took during this process was to continue to express willingness to work with the regulators.

A further jurisdictional concern involves the banning of uranium mining by the Navajo Nation. The December 1992 ban signed by then President Zah allowed uranium mining in Navajo Nation jurisdiction if the miner could prove there would be no harmful effects (Moratorium 1992). Not satisfied with this relatively vague decade old one page executive order, the Navajo Nation Council passed the Diné Natural Resources Protection Act of 2005. This law banned uranium mining and uranium processing, including in situ leach and solution mining in the definition of uranium processing, "on any sites within Navajo Indian Country." This jurisdictional debate is still being resolved.

These two key concepts have shifted the conception of what is Navajo over time. For example, while the traditional Navajo religion continues to be followed, many have converted to other religions. There is a growing population of young Diné that do not speak Navajo. These suggest shifts in the values of the society. While the last two decades are of most concern in the case of Crownpoint, understanding some of the relevant traditional philosophy continues to provide insight on the prevailing contemporary philosophy.

The Navajo word *Hózhǫ́* describes the beauty of the world, in the sense of wholeness, harmony and order[9]. Many of the Navajo traditions and rituals center around maintaining the balance in the world. At the same time, there is acknowledgment that good and evil come from the same source, and the subsequent process of renewal defines the world: the "overriding theme... is the creation of a way of life that will last. But, paradoxically, continuation can be assured only if change is built in to the system" (Farella 1984). Wisdom is understood to be the acceptance of this process of renewal. This has lead to valuing the opinions of the elderly (and presumably wise).

A more differentiated religious spectrum has emerged between those following the traditional Navajo paths and those incorporating that belief system into another, usually Christian, faith. The traditional Navajo spiritual beliefs do not leave room for hurting or leaving the land. According to their faith, people are intimately connected with the Earth that they and their families reside on. This aspect of cultural preservation and change does not leave room for age differences. Many Navajo see the preservation of their way of life as an unending struggle which they are currently losing.

9 The meaning of the word appears to have been mistranslated frequently over the years. Unfortunately, the centrality of the concept to the rest of the philosophy requires a translation. For a fuller description of Navajo philosophy and religion, please see Farella.

According to John Farella, scholar of traditional Navajo philosophy, the concept of power in this society is based on knowledge (1984)[10]. Both the acquisition of knowledge and the use of power are dangerous. One interesting result that partially stems from this concept is that one person will go to great lengths not to articulate another's opinion or force an activity on someone else (Downs 1972)[11]. Related to the above concepts, individual difference within society is seen as not only natural, but a fundamental pillar (Farella 1984).

Since the time of some of these studies, the chapter structure has grown more accepted as a framework for debate (Iverson 2002). Chapter meetings provide a forum for people to express their own opinion, to listen to others, and to carry out various community programs in a town-sized region of Indian Country. This has facilitated the development of the reservation-scale tribal council, composed of chapter delegates (Downs 1972).

The depth and breadth of detail woven into Navajo stories has led some scholars to suggest that myth making is a cognitive process linking "modes of human reasoning, observation and generalization" bordering on the scientific (Zolbrod 2004). This process involves prediction, evaluation, planning and explanation culminating in the creation of a myth. The particularly striking thing about the detailed observational capacity of the Navajo is that the author posits this awareness continues. Zolbrod (2004) speaks of the ability of sheepherders to note when squirrels stop scurrying at the presence of danger. This functional ability is an advantage for protecting livestock and noting the consequences of actions.

Revenue on the Navajo Reservation from natural resources (oil, coal and uranium) sharply increased during the 1955 – 1963 period. The increase corresponded with a shift from herding to wage work. This involved traders recruiting Navajo for jobs that only lasted a few months, so they could

10 While this is not a unique attribute, the articulation of power as knowledge seems uncommon.
11 Downs cites other examples of political settings where men were interpreted as voicing the opinions of their mother's family or wife (Downs p23 1972).

remain home. Hundreds of Navajo miners were employed in terrible conditions with low wages (some lived in chicken coops). The miners were never told of the dangers of open pit and underground uranium mining. Despite all of this, uranium brought $6.5 million to the Navajo Nation in royalties during the 1950s, compared to oil's $76.5 million (Iverson 2002).

By the 1960s, industry was seen as the way to bring needed revenue and employment to the reservation. Unfortunately, uranium mining leases had locked in at low royalty rates. In 1974, the Navajo Nation tried to prevent Exxon from developing a particular uranium lease due to concerns about the impact on the water table, grazing lands, and health of the residents. The unsuccessful suit did increase awareness of the dangers associated with uranium mining. According to Iverson, the ensuing legal cases decreased the amount of uranium mining in the area (2002). By the middle of the 1970s, the dangers of uranium mining had become apparent (Iverson 2002). At the beginning of the 1980s, mining companies were beginning to test in situ solution mining as an alternative to the dangers and expenses of open pit and underground mining. The Diné have continued to struggle to attract industry, with continuing high unemployment rates.

Unfortunately, consequences of the early lack of awareness proved harsh. Tailings from the uranium milling facilities were used in the concrete to make houses, houses that are too radioactive to live in today due to the level of radon in the rock (Pasternak 2006).Birth defects became common for livestock and people who drank water from near the mines, few of which were reclaimed. Some of the uranium miners smoked, the combination of which greatly increased their risk of lung cancer. The national government finally passed the Radiation Exposure Compensation Act (RECA) in 1990, which was to provide $100,000 to underground uranium miners or their families. Unfortunately, the documentation process has proved strict enough to prevent many of the surviving miners access to this compensation.

Over the course of the last two decades, the Navajo Nation Environmental Protection Agency has worked with the US EPA to focus on which of the thousands of toxic sites on the reservation should be cleaned up. After a few exhausting attempts to use the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also the Superfund Law) to enforce the federal environmental regulations, the head of the agency chose to try to cleanup only the worst sites through the Superfund Law (Pasternak 2006). Unfortunately, hundreds of unmarked sites remain, along with houses built of radioactive uranium mine tailings, miners who cannot meet the stringent documentation requirements of RECA, and thousands of post-71 miners and families who cannot yet receive compensation. There have been few comprehensive studies of the long term impact of mining, but given that 50 years ago, the Navajo were studied for their incredible absence of cancer, the outlook looks rather bleak (Pasternak 2006).

In this context, both the 1991 moratorium and the 2005 ban were seen as a way of pushing forward the compensation and reclamation processes, a way of exercising what little leverage the Navajo Nation has to protest the impact of uranium mining on the people. This framework also leaves no space for assuming companies will abide by or the federal government will enforce federal regulations to reclaim land or compensate the Navajo without extensive lobbying and legal battles.

The historical and cultural context presented here have implications for which groups the Navajo may find credible, how they are likely to react to new sources of information, and how the use of local knowledge may come into individual perception of risks and benefits.

Methodology

In order to assess the perception of risk in opening a uranium mine in Crownpoint, New Mexico, an analysis of concerns with the mining proposal, and sources of information was conducted. Material for the analysis derives primarily from interviews on-site with key stakeholders supplemented by a variety of related documents. Interviews were chosen as the primary data collection method because they are the best way to gather in-depth, unexpected information. Understanding the details of community interaction and allowing the residents to express their opinion in their own words facilitates a broader flow of information to the researcher. A single case study was chosen to remain within the funding and time constraints of an undergraduate thesis.

This specific case is an ideal study for a number of reasons. First, it is contemporary. Some participants are still in discussions or litigation with the topic fresh in their minds, and the residents remain divided on the issue. Second, the property rights debate is relevant for other locations in the country. The area includes a mix of trust lands, private property and state and federal lands that are dominated by Navajo residents. Some experts suggest that over 60% of the United States uranium reserves are located on American Indian land (Johansen 1997). Third, if nuclear power continues to be advocated by the federal government without the release of the federal uranium stockpiles, there will be more impetus for companies to try to reopen mines in these areas. Understanding how to provide these communities with the information they would require in order to make an informed decision is imperative. Finally, the twenty year public debate has been documented in a number of different fashions.

Eighteen semi-structured interviews were conducted through careful sampling combined with snowball selection of study participants. The interviews were designed to give each person an opportunity to voice their own perceptions of the risk itself, and to explain how they arrived at their opinion. Interview guides may be found in Appendix I. The initial sample involved contacting a set of organizations identified through the public record, which represented a wide range of interests. Many of these people do not reside in Crownpoint. These affiliated area experts provided additional information on the dissemination of different types of knowledge to various segments of the public, particularly those which their organization was involved in.

Each person in this initial sample was asked to identify residents of Crownpoint who might be interested in the study. As interviews in people's homes proved impractical, the interviews were held at two different times at the Crownpoint Chapterhouse. The first set involved those with business at the chapterhouse, including employees, volunteers and people picking up water from the nearby well. The second set were people who were willing to be interviewed after the January Crownpoint Chapterhouse meeting. These two sets of people actually included several different cohorts in the community, providing insight into the dynamics of the local discussion.

The scope of the residential interviews was limited to the Crownpoint community for a number of reasons. First, they have the longest investment in the project as they will experience the short and long term direct impacts of the mine and processing plant. Second, they have been a continuous part of the debate surrounding the mine for 20 years. Third, the scale is optimal for investigating the dynamics of the dialogue within the community.

There were a number of limitations to this method. Unfortunately, the only allottees available were not affiliated with the Crownpoint Chapter, but were involved in the Eastern Navajo Allottee Association, which includes the Crownpoint allottees.[12] They presented their general view of the proposed uranium mine as representative of what the Eastern Navajo Allottee Association members believe. The largest limitation of this method was the lack of an opportunity to interview a key grassroots group, despite three scheduled interviews. Most of the interview residents preferred to remain anonymous rather than be quoted. As a result, NRC documents were used for quotes.

Finally, the interviews were supplemented with public meeting transcripts, litigation statements and other documents and forums of public debate. A majority of the paper trail volume stems from documents in the NRC's two decade public record. All of these documents were initially scanned for relevance to resident's perceptions. Items highlighted from this process were summarized for use in the

12 The ore bodies around Crownpoint appear to involve 9 allotments (thus about 9 associated families). NRC documents indicate that some of these families religiously attend ENAA meetings.

analysis. Crownpoint Chapter Meeting Minutes and newspaper clippings were also used to gain insight on resident perceptions and local information sources. Resolutions from these public forums were often passed on to the political arena or the NRC.

The hodgepodge of documents represents some of the information available to people in the community, articles that provide regional context and letters from residents to various groups expressing their opinion. Most of these sources are only available in the community. Additional sources that were not used in this study include radio clips and other local newspapers.

Finally, the analysis was completed to understand the dialogue. The main points of each interview with a resident or letters from residents were categorized into concerns about the mine and sources of information. Further grouping revealed an established identity framework for the debate. This process revealed the hierarchy of interests in the community and clarified the sources of information.

Findings: Four Perceptions of Risk

During the interviews with residents and the allottees, three different main perspectives, and one meta-perspective dominated the conversations. The concerns with the mining were based on personal estimations of final exposure risk. Information from newspapers, personal observation and family and friends dominated the discussion, although the credibility of those sources varied.

Concerns Associated with the Proposed Crownpoint Solution Mine

The health risks are of concern to everyone in the community. The most mentioned concern was the potential for contamination of the community's drinking water resource. This reflects the cultural values of a community adapted to the harsh conditions of an arid climate, as described by Murphy: "water is like blood to strengthen our bodies and refresh our minds" (Murphy 1995). Those educated individuals who wrote to the NRC regarding the licensing process noted HRI's inability to fully restore its Texas properties along with Mobil's earlier ISL failure in Crownpoint. This included questioning the science behind HRI's proposal: "We have no assurance that modeling done is accurate. Because of the possible catastrophic results of inaccuracies once mining operations begin, the accuracy of modeling must be assured (Dixon 1995). Supports countered that slightly less than half of the Crownpoint water is already treated for high metal concentrations, and that much of the water is not fit to drink as a result of the natural uranium.

The second largest concern was economics, as discussed above. Half of the comments involve the need for economic development within the community, particularly concerning employment. The other half of the comments laments the lack of monetary benefits to the community as a whole and the limited number of on-site jobs.[13]

These two concerns were followed by concerns about cancer, emergency planning, inadequate health facilities and roads with high accident rates. As one resident mentioned concerning the modeling and scientific power dynamic: one side has been documenting support for themselves for years. They feel that the opposition to the mine has not had adequate time or resources to investigate and present the view that mining will lead to contamination.

Sources of Knowledge in the Community

The two main sources of information are newspapers and family and friends. Newspapers such as the *Navajo Times* and the *Gallup Independent* are commonly available, and have featured numerous articles and opinion pieces on the proposed mine. Interestingly, the newspapers are almost uniformly considered inaccurate. As one woman noted, the journalists do not have first hand experience, but rather base their articles on interviews. However, the papers were perceived to be uniformly more credible than television news. Family members, especially family members who had worked in

13 HRI has promised that 80-90% of the on-site jobs will be available to Navajos only. The projected number of local jobs was around 35 in the FEIS (Reitz #29).

uranium mining or environmental quality fields were considered the best sources of information. Close friends with experience in mining or other personally obtained information (such as particular knowledge about accident rates or hospital facilities) were also seen as credible sources of information. Use of knowledge in the family or friend circles is related to the Navajo concept of community – the family is an acceptable forum within which such divisive topics can be discussed.

Personal experience and direct observation is the next largest source of information. While the percentage of people with personal experience is skewed as a result of the sampling process, a large percentage of people used their own power of observation to create their own cost – benefit analysis. Several people noted the rise and fall of illnesses in the area; many people were sensitive to health effects around old uranium mines. Knowledge about how the community itself operates, and its current unmet needs (such as a dearth of hospital beds) also contributed to resident's perception of risk.

Community groups were the next largest category, used as sources of more formal and up-to-date information. ENDAUM, the local grassroots opposition group, was able to bring a number of professionals to speak to the community, including a doctor and a University of New Mexico geologist. The ENDAUM meetings appear to include a large segment of the community, although participation waxed and waned with time. On the other hand, the Eastern Navajo Allottee Association was able to bring company representatives to speak to its members (although this group has a smaller relevant membership). Chapterhouse meetings appeared to rarely include direct information, but did include announcements about the groups meeting times. One resident said the company came once or twice to Chapter meetings without discussing much information, rather than selling their side of the story.

The second smallest source of information was the Environmental Impact Statement. The reason this documents ranks this high is a result of some bias in the dataset through the inclusion of letters written to the NRC. Some of the people who cited the EIS only read sections they thought were important. They did explain the FEIS in Navajo at a meeting in the community, and several letter writers mention this as their source. Unfortunately, according to another resident, the EIS was significantly different than what HRI had been mentioning at community meetings (Klonowski 1995).

The least important source of information was the world-wide web. Internet use was highest amongst the younger generation. Sources accessed via the internet include Google, articles and even videos. In the community itself, computer access is limited. The Chapterhouse does provide internet access, and has an available (and bustling) computer cluster.

Avoid contentious issues: The Neutrals

The debate over the proposed Crownpoint uranium mine within the community divided families and friends. For the two decades of development of the project, each viewpoint has become more and more entrenched. In the Navajo community, there are certain issues that are mainly discussed within the family, unless the setting is a Chapterhouse meeting, or other appropriate public forum (such as the *Navajo Times* or a local radio station). This contributes to some of the tension within families. In addition, some of the younger people cited an additional strain in the form of the Navajo tradition of elderly people being seen as wise, and not listening to the youth.

The combination of occasionally intense family discussions and the perceived inability to contribute led some youth, particularly residents aged 15 to 29, to stay out of the debate altogether. One woman even went so far as refusing to read the editorials or letters to the editor on the topic in the paper! Not all of the teenagers or people in their twenties took such extreme positions. Another young woman did speak with her relatives about the mine, but her relatives had moved to another state, and this may have impacted how they received information. In families within which the older and middle relatives had reached consensus, the interviewee was much more likely to adopt that tentative stance. While the diaspora of Navajo needs to be acknowledged, most of the Navajo interviewed had lived in Crownpoint or the surrounding area for their entire lives. It would be interesting to investigate how residents with relatives in other cultures may have reacted differently to the situation.

This younger generation is more likely to use new technology to access information. One resident spoke of an emailed video of what Crownpoint would be like if uranium mining happened from the imagination of someone very opposed to the extraction of uranium. Again, this group was more like to use the internet as a resource, and to think of the internet as an additional source of information.

Those Navajo who did not want to be involved in the heated debate refrained from passing judgment as well. Most people admitted to not knowing very much about the proposed mine, and also used this lack of information to support their neutral position. When asked, each person could rattle off a list of sources they would go to if they wanted more information. Unfortunately, the fact that the interviewer was an outsider may have impacted their refusal to voice an opinion.

Use the evidence you can see: Health Concerns

The second main perspective in formulating the risk of the uranium mining project was incorporating personal observations about the history of Crownpoint and uranium mining into the analysis of the plan. These people spoke little about the natural resources management on the Diné reservation in general. Instead, they spoke of the uranium mine "up on the mesa", of the friends they knew who worked in mining, of the related jobs they took mining or reclaiming, of the terrible diseases they saw in people that had not been around 40 years ago. These people remembered the promises of the government and the companies and did not want to repeat the lesson again. As one woman said of HRI, "what makes them think they're different?" For this group, a change in technology does not change what the company will do with the technology nor what the inevitable economic outcome of mining will be. Some of the Navajo herd their animals around the result of that process each day. The attention to detail even extends to the Navajo that work the ambulance shift noting the locations of residents with cancer, or those in the hospital noting the rates of kidney disease. The individuals in this perspective build on their personal knowledge and history of the place to ascertain what the outcome of this new plan will be. This group consistently critically asks, "How will a mine help the Navajo Nation and its people?" and how will the mine help Crownpoint? The opposition also has access to the presenters brought in by ENDAUM. Although the opposition is currently the largest group, this was not true fifteen years ago.

Their opinion of the supporters of the mine is not very positive. As Dixon said, "HRI cares only about it's profits – the rest of us will have to live with what they do... for the rest of our lives" (1995). Other residents speak negatively of allottees just wanting the money and not thinking of the greater good. This entrenched viewpoint suggests the supporters and opposition rarely discuss their perspectives in person, either because social circles do not overlap, or the issue is considered unacceptable for discussion between them.

Developing the economy

The hopeful group sees in the new technology a boost out of the current terrible economic conditions of the reservation into some modicum of financial security and independence. They listen to the possibilities in situ leach mining represents and note how many jobs will be created, how residents can be trained for these jobs and guaranteed some percentage of the positions. This group also envisions better schools for the Diné children, and that the input of money, even in the form of grants the allottees receive will boost the regional economy. The supporters consist of allottees with uranium on their land or residents who think they have a chance at obtaining employment through the project. However, these are people who have each personally weighed the risks, and come out favorably on the side of uranium mining. Like the above evidence group, this group looks around them and sees the economic despair and alcoholism and pushes past that to create common goals, visions and hope for the Diné future. The supporters lament the traditional ways of the opposition, urging them to embrace progress. Although they, too, have a negative view of the other side: "people are envious" and people blame all illnesses on uranium. These visionaries despair that they have become effectively cut out of the political process, and deplore the argument of the opposition as "scare tactics."

Perspective: Seeking balance across the community

Finally, there are the comprehensive thinkers. These community leaders try to balance all of the opinions of the community. They consider the risks and benefits for each person. These people remember the history of each faction. For example, one person spoke of a battle for herd grazing rights on land that led to the division between the Eastern Navajo Allottee Association (ENAA) and the Eastern Navajo Diné Against Uranium Mining (ENDAUM) group. In another instance, they pointed out that the Crownpoint Chapter only included six allottees who would be receiving funds if the project went through. On the other hand, the leaders try to figure out what the actual number of job opportunities would be and consider the costs if the town or the Navajo Nation must pay for the uranium lease rights in compensation. These thinkers recently had an interaction with a cellular telephone company to place a tower near the Chapterhouse. The company needed access to the land. After the ensuing debate and misunderstandings, the leaders spoke poorly of corporations, and seemed to have little trust for the promises offered by outsiders. This experience occurred recently and it's hard to tell from the Chapterhouse meeting minutes what the past Chapterhouse leadership or other community leaders thought of the process and how they apply that knowledge to the case at hand. These high level thinkers were able to obtain information about research on uranium in water and other contaminates being done this year in Crownpoint, even to provide support for such initiatives.

Discussion in the Context of Public Understanding of Science

These findings support the idea that the perception of risk is not just based on an understanding of the scientific and decision making processes, but is based on the information which groups have access to and find credible. First, there is little correlation between knowledge of the scientific and decision making process and perception of risk, as described in Table 5. While the Neutral and Leader groups hint at some correlation, the opposition and supporter of the mine have the same confidence in the decision making process and awareness of the magnitude, with vastly different perceptions of risk. The only correlation appears to be related to uncertainty.

Relevant Parameters for Crownpoint	**The Neutrals: (Interested and Uninterested Public)**	**Health Concerned (Opposition)**	**Building the Economy (Supporters)**	**Balance in the Community (Leaders)**
Confidence in and knowledge of the decision making process	Low	Moderate	Moderate	High
Magnitude of the consequences	Unsure	High	High	High
Risk of Exposure	Unsure	High	Acceptable	High
Uncertainty	High	Low	Low	Moderate
Immeasurable and unknowable factors	Unsure	Moderate	Acceptable	High

Table 5: Comparison of knowledge of scientific and decision making process with perception of risk, uncertainty and unknowable factors. Note how there is little correlation.

On the other hand, sources of information as described by how information was translated from experts to local language and how information was spread does appear to strongly correlate with

Relevant Parameters for Crownpoint	**The Neutrals: (Interested and Uninterested Public)**	**Health Concerned (Opposition)**	**Building the Economy (Supporters)**	**Balance in the Community (Leaders)**
Risk of Exposure	Unsure	High	Acceptable	High
Uncertainty	High	Low	Low	Moderate
Immeasurable and unknowable factors	Unsure	High	Acceptable	High
Translation from expert to public science	Limited access through internet	Access experts through ENDAUM	Access experts through ENAA	Access experts on own initiative
Channels of information dispersion	Newspapers, family and friends	Experienced people, observation and experts	Observation and experts	Multiple

Table 6: Summary of parameters related to source information with respect to the various perspectives in Crownpoint. Note how estimation of risk, uncertainty and immeasurable factors vary with source.

perception of risk. For example, those who relied only on newspapers seem to be the most unsure. Those with access to experts through grassroots groups emphasized the least uncertainty. Personal experiences and observations seemed to be the strongest determining factor on which perspective one had. Of course, these personal observations include conflicts of interest.

Conclusions

People in the community utilized local knowledge to determine if the mine would improve or destroy daily life in Crownpoint, New Mexico. The primary sources of knowledge proved to be a mix of "expert" and local knowledge. The expert knowledge was delivered through journal interpreters after interviews with the grassroots and regional non-profit and company and given less credibility as a result. Local knowledge came in the form of observations and direct experiences in uranium mining or with outsiders. The only direct delivery of expert knowledge was controlled by local distinct organizations. As no one interviewed attended both meetings, it would seem that people got to hear one side of the story.

From these perspectives, it appears that local knowledge, such as personal or family experience and personal observations, are the strongest determinant on an individual's perspective of risk. On the other hand, access to just one set of experts led people to believe there was little uncertainty as they understood the risk. The prevalence of relying on direct observation and personal experience, presents a challenge for mining companies intending to develop properties in experienced mining communities: the mistakes of the past will not soon be forgotten. The observations of the visionaries present a hope that companies could tap into to develop improved corporate responsibility programs on the local level. On the other hand, opposition groups can tap into this history.

The reliance on the observations of family and friends suggests a strong community network. Future studies could illuminate the working of this network, in the context of political or decision making knowledge flows. Unfortunately, there seems to be a dearth of forums for public debate and sharing of information across groups. The youth feel unheard, and there is little communication across the local organizations. The control of expert knowledge into the community presents an independent conundrum. While the Nuclear Regulatory Commission may be in the best position to address local knowledge concerns, the credibility of the NRC (or the federal government in general) is very low given the history of uranium mining in the area. In addition, as the internet becomes more widespread, sources of information are likely to shift. Despite the local knowledge and added context, the mine is still moving forward. The political power of the community may have contributed to the 2006 ban on uranium mining, however the only other avenue for community control is through the legal system.

As mining on allotment and reservation land increases with the high prices of metals, additional sources of expert information and mechanisms for sharing experiences in the community need to be highlighted. The stakes for the residents on these lands are high. While the government tries to determine what level of risk is acceptable, to fully embrace environmental justice, the community needs to be given all of information, and make a decision for themselves.

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APPENDIX I: Draft Interview Instruments

Interview Guide for Community Participants

1. Please tell me a bit about who you are, your background and experience with the Crownpoint/Churchrock debate.
2. Have you formed an opinion? What do you think?
3. What information did you use to make that opinion?
4. Did you find any sources convincing? What about them was convincing?
5. Who did you find credible / believable?
6. Did you read the newspapers? What caught your attention?
7. What scientific information did you learn from the company? Was it believable? What about it was(n't)?
8. What scientific information did you learn from the SRIC? Was it believable? What about it was believable?
9. What did you learn from other community members? Was it believable? What about it was believable?
10. (other businesses, Nuclear Regulatory Commission, NM water quality department, Navajo Nation EPA, Federal EPA, ENDAUM, NM Environmental Law Center, UNM scientists, other university scientists?)
11. When you have questions about the environmental impact of the mine, who do you ask?
12. Did community meetings or newspapers influence your opinion? How?
13. What knowledge do you wish you had?
14. Anything that you would like to share?

Interview Guide for Civil Society Organization Members

1. Please tell me a bit about who you are, your background and experience with the Crownpoint/Churchrock debate.
2. What do you see as the role of your organization in the debate with respect to scientific information?
3. What sources of science in this debate do you find to be the most compelling? What makes them compelling?
4. How do you try to educate the community on the science?
5. What methods of presenting information do you find to be the most effective? What makes them effective?
6. What additional information do you wish you had access to?
7. What information do you think is missing from this debate?
8. Who do you think people trust when it comes to information? What makes them trustworthy?
9. What role do you think the company has had in providing information? What role do you think they should play?
10. What role you you think the EPA or NRC has had in providing information? What role do you think they should play?
11. Do you think the community is fully informed? What do you think made them that way?
12. Anything else you would like to share, or that you think I'm missing?

Interview Guide for Company Representatives

1. How does HRI try to get information to the people of Crownpoint?
2. What local organizations have you presented to? What works best (graphics, copies of

textbooks, copies of affidavits?)

3. Do you think local newspapers have accurately covered the proposed mine?
4. Do you think T.V. news has accurately covered the proposed mine?
5. Do you think the NRC hearing science and discussions reaches the people of McKinley County? How / what prevents?
6. Where do you think ENDAUM gets their information? SRIC?
7. Do your local employees receive any training? What type?
8. The oxidation process usually releases a number of other toxic substances, is this ever discussed on the community level? Why / why not?
9. What modeling is used to negate the channel argument?
10. Are there cases when you would not use the 400 foot industry standard for monitoring wells?

Appendix II: Additional Geology Figures

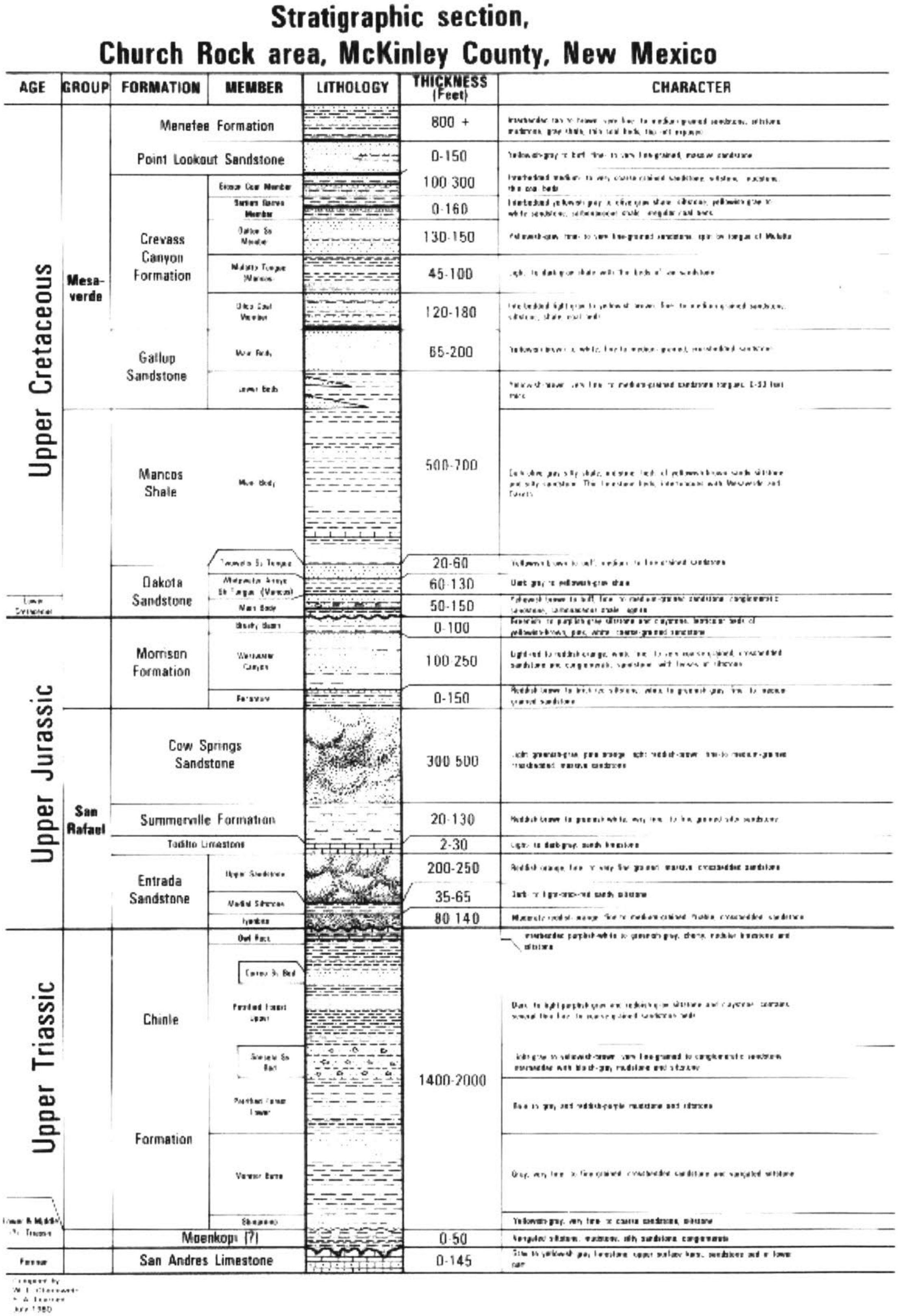

Illustration 5: Stratigraphic Section of Church Rock Area, note depth of Westwater Canyon Member (Rautman 1980).

$2FeS_2 + 7.5O_2 + 5H_2O \rightarrow 2FeOOH + 4SO_4^{2-} + 8H^+$
$2FeS_2 + 7.5O_2 + 4H_2O \rightarrow Fe_2O_3 + 4SO_4^{2-} + 8H^+$
$2FeS_2 + 2HCO_3^- + 2H^+ + O_2 \rightarrow 2FeCO_3 + 4S^0 + 2H_2O$
$2FeSe_2 + 2HCO_3^- + 2H^+ + O_2 \rightarrow 2FeCO_3 + 4Se^0 + 2H_2O$
$2FeS + 4.5O_2 + 2H_2O \rightarrow Fe_2O_3 + 2SO_4^{2-} + 4H^+$
$4FeS_2 + 6H^+ + 6SO_4^{2-} \rightarrow 4Fe^{2+} + 7S_2O_3^{2-} + 3H_2O$
$2FeCO_3 + 4S^0 + 2.5O_2 + H_2O \rightarrow 2FeS_2O_3^+ + 2HCO_3^-$
$2Fe_3O_4 + 0.5O_2 + 3H_2O \rightarrow 6FeOOH$
$2FeCO_3 + 0.5O_2 + 2H_2O \rightarrow Fe_2O_3 + 2HCO_3^- + 2H^+$
$Fe^{2+} + 0.5O_2 + 2.5H_2O \rightarrow Fe(OH)_3 + 2H^+$
$S_2O_3^{2-} + 2O_2 + H_2O \rightarrow 2SO_4^{2-} + 2H^+$
$UO_2 + 2HCO_3^- + 0.5O_2 \rightarrow UO_2(CO_3)_2^{2-} + H_2O$
$USiO_4 + 2HCO_3^- + 0.5O_2 + H_2O \rightarrow UO_2(CO_3)_2^{2-} + H_4SiO_4$
$As_2S_3 + 7.5O_2 + 5H_2O \rightarrow 2HAsO_4^{2-} + 3SO_4^{2-} + 10H^+$
$Se^0 + O_2 + H_2O \rightarrow SeO_3^{2-} + 2H^+$
$Se^0 + 1.5O_2 + H_2O \rightarrow SeO_4^{2-} + 2H^+$
$2VO + 1.5O_2 + 2H^+ \rightarrow 2VO_2^+ + H_2O$
$MoS_2 + 4.5O_2 + 3H_2O \rightarrow MoO_4^{2-} + 2SO_4^{2-} + 6H^+$
Sorption Reactions (≡XOH represents a mineral surface site)
$\equiv XOH + UO_2(CO_3)_2^{2-} + H_2O \rightarrow \equiv XOUO_2OH + + 2HCO_3^-$
$\equiv XOH + HAsO_4^{2-} \rightarrow \equiv XOAsO_3^{2-} + H_2O$
$\equiv XOH + H_2AsO_3^- + H^+ \rightarrow \equiv XOAsO_2H_2 + H_2O$
$\equiv XOH + SeO_3^{2-} + H^+ \rightarrow \equiv XOSeO_2^- + H_2O$
$\equiv XOH + VO_4^{3-} + H^+ \rightarrow \equiv XOVO_3^{2-} + H_2O$

Illustration 6: Examples of reactions that may occur during in situ mining. This table is not comprehensive. Note how molybdenum, arsenic and selenium come into solution. Table from Davis et al. 2007.

APPENDIX III: Tables of Oil and Uranium Economic Data

Table 1: US Oil Supply Numbers

	Oct 06 monthly thousand barrels	***% of Total Imports***	***% of Total US consumption***
OPEC Oil[14]	171,260	41.46	26.62
All US imports	413,052	100	64.19
Total US oil consumption	643,452		100

Data from Energy Information Assocation Statistics, Department of Energy. From the Petroleum Product Supplied and US Imports by Country of Origin, <http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html>.

Table of US Energy Consumption Estimates

	2004 US Totals	***2030 US Total***	***Percentage Increase***
Total US Energy Use (quadrillion btu)	100.414	133.88	33.33
Carbon Dioxide Emissions (million metric tons)	2248.1	8114.5	260.95

"Energy Consumption by Source, Selected Years, 1949-2005." *Annual Energy Review* 2005. Energy Information Administration. 2005. <http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_9.pdf>.

"Energy Consumption by Sector and Source" *Annual Energy Outlook 2006 with Projection to 2030/* Energy Informations Association. <http://www.eia.doe.gov/oiaf/aeo/pdf/aeotab_2.pdf>.

"Historical Data Series: Energy-Related Carbon Dioxide Emissions from the Residential and Commercial Sectors by Fuel Type, 1949-2005." *US Emissions Data*, Energy Information Association. <http://www.eia.doe.gov/environment.html>.

14 According to the US Energy Information Association, "among the top 20 oil reserve holders, 8 are OPEC member countries that together account for 65 percent of the world's total reserves (EIA International 2006)."