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TITLE: URANIUM, WATER AND THE ENVIRONMENT: NEW MEXICO'S URANIUM LEGACY AND FUTURE

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Uranium, Water and the Environment: New Mexico's Uranium Legacy and Future

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The Energy Act of 2005 provides a number of incentives to foster a new generation of nuclear power in the United States. Those incentives, if successful, will lead to increased demand for uranium fuel, another energy source for which we are largely reliant on foreign sources at this time. New Mexico has the second largest uranium reserves in the U.S. (after Wyoming). If New Mexico's uranium resources are to be extensively exploited, it will almost certainly involve in-situ solution mining, a process that will generate numerous environmental questions. Considerable scientific and technological research needs to be done to put New Mexico in a position to address these issues that will be raised regarding resolution of legacy issues, as well as environmental and social impacts of renewed uranium mining.

Uranium exploitation, potentially a fundamental component of the energy needs of the citizens of New Mexico and the nation, will also have to accommodate concerns regarding water and environmental degradation. Surface and groundwater quality and quantity issues must be addressed because water will be used in any uranium development.

Energy and water projects will provide fundamental insights into regional surface geology, subsurface 3-D geological structure, economic uranium resources, water quantity and water quality. Additionally, expanded knowledge in these areas will bring substantial benefits to New Mexico in the fields of regional water supply, remediation needs, geological hazard evaluation for land use planning and other mineral development (oil and gas, coal, industrial minerals, aggregates, metals).

Compilation of all available existing information on the state's uranium deposits and associated rock and water geochemistry provides a catalog of known uranium resources and previous mining activities. Geochemical studies of contaminants in soils, surface water and groundwater in areas impacted by mining and surrounding areas may provide more realistic baseline data. Imprtantly, these studies can also be utilized to determine anthropogenic verses natural contamination in a 3-dimensional framework that considers geologic setting and history of mining activity. In addition, detailed mapping and modeling of aquifer units in potential mining regions will aid in understanding water pathways and to answer questions about potential transport of contaminants. Development of improved in-situ recovery technologies for extraction of uranium from subsurface solutions would improve the efficiency of mining processes, to address the specific suitabilities of New Mexico ores to solution mining, and to improve the efficacy of water remediation programs.

Specific areas of activity envisioned are:

1. Databases – cataloging and digitizing uranium resource and mining information already compiled; collecting any still-available uranium information from

previous industry efforts; collecting, consolidating and digitizing information from other state and Federal agencies.

2. Resource/Contamination assessment – surface mapping of geology and rock geochemistry in the Grants Mineral Belt; create a summary of older generation of data and update with new generation of information; and evaluate water chemistry including tracers.
3. Baseline studies – will focus on natural and existing anthropogenic contaminants in soils, surface water and groundwater including an examination of previous uranium mining in the state and its environmental impacts. These studies will include information from prior remediation projects and Nuclear Regulatory Commission (NRC) records. The baseline project will include compilation of a statewide database of existing data and new water quality information, possibly establishing a statewide water quality data center.
4. Hydrogeology, aquifer characterization and modeling – will involve delineation and mapping of aquifer units, aquifer compartmentalization and modeling of directions and rates of fluid movement in order to predict potential in-situ solution mining impacts and better assess the likely pathways and transport direction for known contaminant plumes from legacy mining.
5. Technologies for extraction and treatment – includes an overview of current in-situ recovery and conventional mining technologies, processes for post-mining water cleanup, and possible innovations that address other economic elements within the context of efficient mining.
6. Education and outreach – information generated needs to be available to the citizens of New Mexico, the regulatory community and policy makers. Web-accessible databases for specialists and regulators complimented by reports generated for non-scientists. The data can be utilized by regulatory agencies and decision makers to set standards to insure that future mining operations do not lead to adverse environmental impacts. This research will be collaborative in the broadest sense with multiple university and state agency partnerships; including multiple paths for student involvement in all aspects of research objectives. Student workers will be an important component of the research. This will provide training for a new generation of scientists knowledgeable about the geology, hydrology and geochemistry of the district and its relationship to human health and environmental contamination.

1. DATABASES

Objectives

This component of the project will catalogue and digitize uranium resource and mining information; collect any still-available uranium information from previous industry efforts; collect, consolidate and digitize information from other state and Federal agencies; and place all of this information into GIS, web-accessible formats.

Background

Currently, the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) at New Mexico Tech is in the process of converting years of archival uranium mining data (information on location, production, reserves, geology, geochemistry, resource potential, mining history, development and ownership) into a relational database that can be integrated with ArcGIS and available to the public on the internet. Existing data and databases at the NMBGMR include a GIS database of uranium mines, prospects, deposits, and mills in New Mexico; a bibliography of the geology, hydrology and mineralogy of the state and a specialized library collection of uranium publications; a map database of geological, hydrological, gravity and mine maps; and collections of geophysical well logs and historic photographs.

Additional information from other private, state and federal agencies could be added to the database to provide information that will aid in:

- Identifying uranium mines, prospects, deposits and mills in New Mexico.
- Monitoring uranium production and resource data.
- Evaluating potential areas for uranium-resource development.
- Evaluating baseline conditions of uranium in the environment.
- Identifying and evaluating possible environmental concerns, such as physical hazards like indoor radon, regional exposure to radiation from mines, and point-sources of possible pollution in areas of known uranium deposits.

2. RESOURCE ASSESSMENT

Objectives

The Grants Mineral Belt saw most of the development during previous mining efforts and is currently the focus of most of the industry interest.

Background

New Mexico played a dominant role in historic domestic uranium production in the United States and ranks second to Wyoming in uranium reserves. Although the period of high production declined in the early 1980s, the recent increases in the price of uranium and the increasing prices of oil and gas have initiated a period of renewed interest in domestic uranium exploration, and potentially production, in New Mexico. For that reason it is important to reassess the geologic potential of uranium resources in our state. Ore occurrences that are amenable to conventional surface and underground mining might not be considered viable deposits for in-situ leaching due to ore mineralogy and distribution, host rock composition and characteristics, or hydrological considerations. However, new assessments would also take into account the improved technologies for mining of such ores by in-situ leaching.

Work Plan

The San Juan Basin in northwestern New Mexico was the main focus of past uranium exploration and mining in the state. It hosts the world-class Grants Mineral Belt and the smaller but historically important Shiprock mining district. Deposits in these areas are hosted mainly in sandstones in the Westwater Canyon, Salt Wash and Brushy Basin Members of the Morrison Formation in the Grants, Gallup, Crownpoint, and the Shiprock areas, and in the Jackpile Sandstone near Laguna. Because the San Juan Basin is also a producer of natural gas and oil, recent drilling has increased our subsurface knowledge of this area since the early 1980s. To reassess the uranium potential in this area, detailed geological cross sections of the basin will be constructed using this recently acquired subsurface geologic information. A similar project was started by the federal Atomic Energy Commission and the USGS, but was never completed. New geological and geophysical data from oil and gas drilling can be incorporated to determine the distribution of favorable ore horizons, the position of oxidation-reduction fronts (critical for the transport and deposition of uranium), and the structural and sedimentary controls on fluid flow.

Given advances in solution mining, areas of favorable geology at greater depths can now be considered as potential ore hosts. Ore mineralogy descriptions, host rock reactivity, host rock stratigraphic continuity, and other relevant factors of uranium-bearing areas would be provided to assess and quantify the leachability of these types of ores. Uranium ore is often deposited in multiple episodes over time and radiometric dating can give us a better understanding of these various ages of emplacement (which can have significant impacts on successful extraction). Site-specific field studies that may include field mapping, core and log examination and characterization, petrography, and additional geochemical sampling and evaluation can be conducted to fill in data gaps in these districts.

3. BASELINE STUDIES

Objectives

A comprehensive assessment of soils, surface waters and groundwaters of the Grants Mineral Belt are needed to evaluate both the natural and anthropogenic uranium contamination currently present if there is to be a future uranium industry in New Mexico. This will require compiling data collected from prior remediation projects.

Background

Significant quantities of uranium were actively mined in New Mexico from the 1950s through the early 1980s. Both open-pit and conventional underground mines were utilized to access the state's rich uranium resources before the industry largely shut down in the 1980s.

Because early mining activity had little state or federal government oversight, a legacy of soil and water contamination and associated health effects is found in many communities associated with previous uranium extractive operations. In addition to anthropogenic uranium contamination, ground and surface waters have interacted with near-surface ore bodies, producing waters with uranium concentrations higher than the 30 ppb (μg/L) drinking water standard that is mandated by both the New Mexico Environment Department and federal Environmental Protection Agency.

Apart from supplying invaluable geochemical data on uranium resources, this survey of New Mexico's natural resources can also provide an opportunity to collect a statewide database on known and emerging contaminants such as arsenic, lead, selenium, and other metals. By taking a proactive stance to identify and quantify potential hazards, future environmental impacts can be minimized by creating geohydrologic models of the ore bodies and surrounding rock units. Also, providing the geologic data in a clear and understandable manner to the layman may also make an emerging uranium industry less threatening.

Work Plan

Areas of known past ore production will be sampled extensively to determine the environmental impact left by that production. This data will be collected into a comprehensive database to be utilized for current and future hazard mitigation.

Water samples collected from existing drinking water wells and from surface waters around the state will have their uranium concentrations measured by inductively-coupled plasma mass spectrometry (ICP-MS). The laboratories associated with NMBGMR/NMT have extensive background in uranium analyses, including isotopic determination. Additionally, other potential pollutant elements, such as arsenic, lead, mercury, chromium, and selenium will be determined by ICP-MS for minimal additional cost. Other basic chemical analyses of the water will be conducted using flow-injection analysis, ion-chromatography and inductively coupled plasma optical emission spectrometry (ICP-OES). In addition to water analyses, comprehensive soil and rock sampling can provide information on surficial distribution of uranium in the environment. This data can be utilized to determine baseline values as well as anthropogenic sources of contamination. These analyses can also provide information regarding the geological sources of the water in the drinking water wells, an important parameter that can be used to assess mineral resources and to locate future wells at safe depths.

Many past uranium mining efforts took place on Diné tribal lands. Uranium tailings still exist in these areas and could be causing air and water contamination. Therefore, an assessment of uranium concentrations on Diné lands is especially important. This will require the consent and collaboration of the Diné community. This would be an excellent opportunity to bring in faculty and students from Diné College as collaborators.

4. HYDROGEOLOGY, AQUIFER MAPPING AND MODELING

Objectives

The primary objective of the aquifer mapping is to provide geologic and hydrogeologic data for the Grants uranium region and later for other areas of perspective exploitation. This data will allow a variety of interests to properly evaluate the technical and economic feasibility of uranium mining in a variety of hydrogeologic settings, and evaluate potential environmental effects, ways to avoid negative impacts, and remediation methods associated with such mining.

Societal Benefits

If in situ recovery (ISR) technologies are applied to New Mexico uranium deposits, then studies of the geology and hydrogeology of the associated aquifer systems, adjacent strata and units for wastewater disposal are essential. Aquifer mapping provides impartial, quantitative data on baseline water quality, regional groundwater flow, groundwater storage, water chemistry, geologic and geochemical complexities and can help distinguish anthropogenic (human-caused) hydrologic patterns from natural hydrologic patterns.

A clearinghouse of uranium-related geology and hydrogeology data will provide decision-making tools to a great variety of interested parties. Geologic feasibility and potential impacts of ISR mining on the environment should be carefully considered. Various aspects of this project, from field mapping to water level measurements, may require assistance and support from local communities. These studies therefore could provide a useful link between scientists and communities that could facilitate discussion about the issues related to a future uranium industry and ISR operations.

Work Plan

Prior to beginning any ISR uranium mining operation, a thorough assessment of the ore-bearing units and the surrounding hydrogeology should be completed. Most geologic and hydrogeologic systems are exceedingly complex and therefore difficult to evaluate and model without high-quality data. A number of conditions in the geologic environment influence the suitability of any uranium deposit for ISR mining in an environmentally benign manner. They include the following, which will be evaluated:

- Small-scale stratigraphic variability within the ore body paleochannels leading to poor confinement of lixiviates, undetected excursions, and leaching problems.
- The complex influence of geologic faults on groundwater flow.
- The existence of bedrock fractures that cause unpredictable contaminant migration.
- Geochemical and biological complexities involving the groundwater, aquifer, and aquitards.

After the ore body has been mined, it is necessary to restore the groundwater quality to pre-mining levels. This typically involves the chemical treatment of the affected area to remove the residual solutions and chemicals, and immobilizing any elements that have been dissolved into solution, such as arsenic and other trace elements. The most critical aspect of any restoration attempt is attaining the pre-mining groundwater quality. This requires extensive background (pre-mining) groundwater quality data, to allow the determination of restoration standards for all quality indicators, such as sulfate, pH, total salinity, uranium, radium, arsenic, molybdenum, selenium, and other elements.

A comprehensive, three-phase assessment of the geology and hydrogeology of the Grants mineral region needs to be undertaken in order to provide high-quality, quantitative information.

<u>Phase 1) Develop 3-D geologic model of the sedimentary system.</u>

a) produce digital geologic map and soils map at an appropriate scale using existing maps and new mapping, if needed;
b) compile existing borehole geologic and geophysical data to further define ore zones and adjacent aquifers and aquitards, and collect and process new data, where needed;
c) use geologic and geophysical data to identify faults, stratigraphic contacts and heterogeneities, evidence of paleo- or modern fluid flow, and geochemical/mineralogic anomalies; and

d) create a 3-D visualization geologic model using subsurface correlations and maps.

Phase 2) Characterize regional and local groundwater systems that encompass ore zones at watershed or basin scale.

a) compile existing hydrogeologic and hydrologic data, and collect new data where needed (water levels, hydraulic head gradients, etc.);
b) collect new hydrochemical data (general chemistry, chemical tracers, isotopes, dissolved gases, ages, etc.) to characterize the flow path and apparent age of the regional groundwater system;
c) define extent of aquifer and aquitards that encompass ore zones; and
d) characterize microbial (bacterial) activity in the system.

Phase 3) Develop local to regional 3D hydrogeologic conceptual models that encompass the ore zones from 1 and 2 above, and apply to mine site issues.

a) create a 3-D hydrogeologic visualization model;
b) identify potential lixiviate excursion and exposure scenarios to domestic and other supply wells, streams or springs;
c) identify potential deep aquifers or injection zones for deep disposal of excess water;
d) modeling of ground water flow in non-homogeneous anisotropic formations to improve contact between leach solutions; and
e) Design of injection-collection well systems to direct flow to uraniferous materials.

5. TECHNOLOGIES FOR EXTRACTION AND TREATMENT

Objectives

Any resumption of large-scale uranium extraction in New Mexico will almost certainly result in releases of elements, compounds and solutions to groundwater and possibly surface waters. Since both are routinely used for drinking water by state residents, it is critical that the state of technology for mining uranium and removing it from drinking water be assessed.

We propose an assessment of the potential and the pitfalls associated with in-situ recovery uranium extraction. This will involve assessing the potential impacts to waters as well as an assessment of water needs for the industry.

Background

Uranium deposits in the U.S. are mainly of the sandstone-hosted roll front deposit type, which developed at the oxidation-reduction interface within sandstones. They are located in the Colorado Plateau, Wyoming basins, and the Texas Gulf coastal plain and are generally in the form of uraninite (UO_2) or coffinite ($USiO_4$) mineralization. The sedimentary deposits in New Mexico that best meet the criteria for an economically viable ISR uranium ore body are found principally in sandstones paleochannels (old river beds) of the Morrison Formation in the southern San Juan basin.

In-situ leach (ISL) or recovery (ISR), also known as solution mining, is the primary process for uranium mining in the U.S. and generates over 80% of the annual U.S. uranium production. ISR mining has been extensively used in south Texas and Wyoming. Though the ore bodies are generally relatively deep, the Grants Mineral Belt is the principal target for future ISR uranium mining in New Mexico. In the late 1970's and early 1980's, Mobil conducted a successful pilot ISR project near Crownpoint, NM that led to design, licensing and construction of a full-scale project. However, the project was never completed because of the drop in uranium prices. The Crownpoint mineral rights were acquired by Hydro-Resources, Inc. (HRI), and they have applied for a license to develop this property using the ISR process with the NRC. Additional nearby sites within the state have been proposed for ISR mining.

The technique of ISR solution mining is essentially a groundwater mining operation, and it is performed by pumping an oxidizing, aqueous, leaching solution (called lixiviate) into a series of injector wells through permeable (typically sandstone), uranium-bearing subsurface rocks. The lixiviate strips the uranium (and other elements) from the sand grains. The pregnant solution is then pumped to the surface at extraction well and processed to remove the uranium, and the barren lixiviant is re-used. ISR operations typically withdraw more solution than injected, in order to attempt to capture all of the injected lixiviate. This excess water requires disposal, typically by injection into a deep aquifer. Information about the mineralogy of ore-bearing rocks and confining layers, and the properties of all adjacent aquifers, are crucial to safe and profitable uranium extraction, and for determining the appropriate post-mining aquifer restoration method.

In areas where the groundwater is potable and is used for domestic and municipal purposes, ISR has the potential to impair water quality for tens to hundreds of years. The most critical part of any ISR process is to effectively contain and control the movement of the chemical solutions within the aquifer(s), both during and after mining operations. Problems and difficulties at ISR mines arise due to unrecognized, complex geological and hydrogeological environments, unexpected geochemical conditions and microbiological interference; all of these can cause engineering problems that result in contamination of groundwater. In part, the success of any ISR operation depends on possessing impartial, detailed characterizations of the geology, geochemistry, hydrogeology, and hydrology of the mining site. Such information is valuable to industry when exploring for suitable sites, the public and NGOs for evaluating proposed mining operations, government regulators when considering permits and plans, and engineers who design the mechanical and chemical systems at the mines and extraction plants. Unlike open-pit and underground mining, ISR doesn't generate mine tailings and waste rocks, which are major sources of soil and groundwater contamination. In addition, ISR has the potential to clean already impaired water supplies. For example, groundwater in the area around the Homestake Mill in the Ambrosia Lake mining district has dissolved uranium concentrations making the water unuseable for drinking or irrigation. Mill sites were commonly located on alluvium to allow for fast dewatering of ore/tailings piles. The process of dewatering the tailings piles also resulted in the dissolution uranium into the groundwater. As long as the piles are exposed, they have potential to impact water quality in the region.

Work Plan

In addition to the work in the section on hydrogeology, aquifer mapping and modeling, the proposed study would include work in two areas: 1) geochemical investigations to improve selective recovery of U and other commercial elements while limiting impact on the aquifer and 2) geochemical investigations of methods to achieve aquifer restoration after mining is complete.

Geochemical Investigations related to Enhance Uranium Recovery:

Current ISR processes use very simple lixiviants regardless of the mineralogy; a native ground water solution containing an oxidant (usually oxygen), a complexing agent (carbonate) and sometimes a surfactant. It is believed that with improved knowledge of the geochemistry and mineralogy, the leaching solution can be tailored to increase the rate of U dissolution thereby accelerating the mining process and likely increasing the total U recovery. Examples of these investigations might include:

a) Fundamental studies of the oxidation and dissolution process for important U minerals
b) Kinetic studies of dissolution in non equilibrium systems
c) Enhancement of U extraction from the lixiviant through use of improved separation processes such as IX and membrane-based selective extraction processes.
d) Recovery of other valuable constituents from the lixiviant.

Geochemical Investigations related to Aquifer Restoration:

Perhaps the major public concern about ISR mining is its impact on ground water resources. This is particularly true in the southwest where water is increasingly scarce. While one of the benefits of ISR mining is minimal consumptive water use, it may impact ground water quality. Therefore, future ISR projects must be able to demonstrate that post mining restoration activities will return the ground water to its original quality. Examples of these investigations might include:

a) Development of ground water restoration procedures possibly to include aquifer flushing, selective extraction of problem contaminants (i.e., As or Se), and chemical or biological methods to re-establish reducing conditions.
b) Theoretical, laboratory and field studies of the long-term stability of ground water restoration methods.
c) Application of reactive transport models to predict long-term impacts of ISR mining on ground water quality.
d) Development of ground water monitoring methods and procedures to improve public confidence in restoration strategies.

6. EDUCATION AND OUTREACH

A fundamental component of this program will be education and outreach. The major purpose of this project is to compile and analyze data and information that will be useful to a wide variety of interests associated with potential uranium development in New

Mexico. To be useful, this material must be available to all, and equally important, it must be understandable. This means it must be searchable and compatible with a variety of electronic formats.

Education and outreach will take place during all phases of the project. We would propose that interested students from Diné College would be recruited and paid to collect water and soil samples on the Diné reservation. Their knowledge of reservation lands and their ability to interface with the Diné community will be crucial to the success of the project in this region of New Mexico. Once analyses are complete, the Diné College students will be given the task of reporting on and interpreting the results at tribal and/or community meetings. All results will be made public.

As the primary work is completed, summary reports and supporting data will be compiled and disseminated. Publications, maps and databases will be generated. Potential methods for information dissemination include symposia, town halls, and meetings. In addition, a website for this material may be created, or a webpage developed that is located in or linked to one or more existing websites. This may include an interactive forum. In addition, long-term monitoring and ongoing studies and data collection will require that some data sets be updated periodically with the new information. This may generate new conclusions or the need for additional studies, which also will be made public.