In-Situ Recovery of Uranium

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As an alternative to conventional underground or surface mining operations, uranium deposits increasingly are being mined by in-situ recovery (ISR). ISR works well for redistributed uranium present as a coating on the sand grains in many sandstone deposits because the uranium is relatively soluble when subject to oxidizing conditions. Where the hydrogeology of the deposit is favorable, such as in permeable, saturated, confined sandstone deposits with relatively flat-lying beds and low hydraulic gradients, uranium can be recovered by circulating a solution through the deposit rather than by bulk excavation. Typically, 60 to 80 percent of the uranium in the deposit can be recovered. ISR offers many advantages over conventional mining, including a lack of tailings piles, minimal disruption of the land surface and thus minimal surface reclamation needs, reduced labor requirements, and overall lower costs.

About 30 ISR operations and numerous pilot projects have been licensed and operated in the United States since the early 1970s, particularly in Nebraska, Texas, and Wyoming. New operations are proposed in New Mexico, Texas, and Wyoming.

Running the Formation Process Backwards

ISR makes use of the hydrologic and geochemical properties of a uranium-bearing sandstone aquifer to recover uranium by essentially running backward the process that formed the uranium deposit in the first place. As described by Yancey (page 20), roll-front uranium deposits form in sandstone when oxidized water carrying dissolved uranium encounters a reducing zone in the aquifer, where the uranium precipitates and accumulates over time (see diagram, right).

In ISR, local groundwater fortified with sodium bicarbonate or gaseous carbon dioxide and oxygen (the "lixiviant") is injected into the ore body. Extraction wells draw the lixiviant through the formation, oxidizing and dissolving the uranium, and back to the surface, where the solution undergoes ion exchange to remove the uranium. The uranium-depleted water is returned to the wellfield for refortification with oxygen, then recirculated back to the injection wells. This process continues until no more uranium can be economically recovered. Sets of injection wells are paired with extraction wells to ensure good flow through the deposit; their arrangement is based on the hydrogeologic conditions of the site (see page 30).

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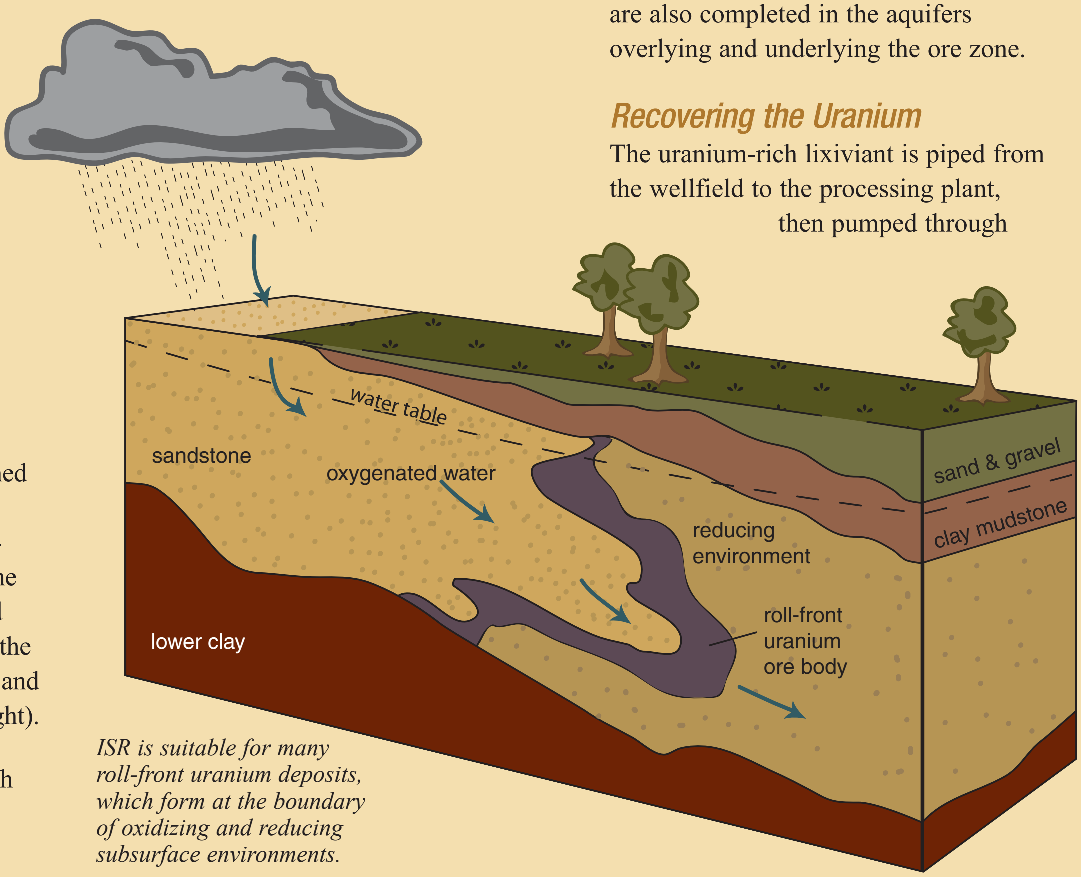

ISR is suitable for many roll-front uranium deposits, which form at the boundary of oxidizing and reducing subsurface environments.

Production wells are operated at the maximum continuous flow rate achievable for the deposit. Flows typically range from 20 to 100 gallons per minute. In addition to the use of paired wellfield injection/extraction patterns, injection into the wellfield is maintained at a flow rate around one percent less than the extraction rate to create a hydraulic gradient that draws groundwater outside the ore zone into the wellfield and keeps the lixiviant from migrating outside the production zone. Flow rates for the injection and production wells are monitored regularly to assess operational conditions and mineral royalties.

The groundwater is extensively monitored to demonstrate that the lixiviant remains within the production zone. Monitor wells are completed in the ore-bearing aquifer, encircling the wellfield at about 400 feet from the peripheral production or injection wells and around 400 feet apart, according to industry convention (and Texas standards). Monitor wells are also completed in the aquifers overlying and underlying the ore zone.

Recovering the Uranium

The uranium-rich lixiviant is piped from the wellfield to the processing plant, then pumped through ion exchange resin columns where the uranium is recovered and further processed into yellowcake, a uranium concentrate. Uranium-depleted water from the resin columns may be filtered to remove particulates before recirculation.

In cases where uranium ore deposits are too small to support a full-service process facility, or portions of the wellfield are so distant that piping water is not practical, remote ion exchange (RIX) may be employed. RIX uses ion exchange columns at the site to recover uranium from the leachate stream, but the uranium-loaded resin is trucked to a central plant where the uranium is recovered. The stripped resin is returned to the RIX site for reuse.

When There's No More Uranium

Once the economic recovery limit of a mine area is reached, lixiviant injection is stopped and the affected groundwater is treated to return its quality to levels defined by regulatory standards. This is generally accomplished by circulating nonfortified groundwater through the production zone using the same injection-extraction wellfield configuration as was used during production. The extracted water is purified in an ion-filtration process such as reverse osmosis treatment (RO) and the clean water is recirculated. The concentrated brine byproduct of RO is about 25 to 35 percent of the feed volume.

Alternatively, the wellfield may be "swept" by continuously pumping water from the extraction wells, drawing groundwater in from beyond the mineralized zone to replace the pumped fluid. Pumping continues until the desired water quality is attained. Water quality improvements by this method are achieved more slowly than by RO, and large amounts of groundwater are consumed. After any uranium in the pumped water is recovered, the water is disposed of in deep waste injection wells, but well capacity limits the rate of restoration.

Aquifer quality restoration goals are initially established by state water-quality regulators, usually on a parameter-by-parameter basis, with the primary goal of restoring all parameters to average pre-mining baseline conditions. Although the ISR process does not introduce new chemical species to the groundwater system, it does elevate the concentrations of some that were already present, such as calcium, sodium, chloride, bicarbonate and uranium. If it is not feasible to return all parameters to their baseline concentrations, the secondary goal of aquifer restoration is to return water quality to the maximum concentration limits as specified in U.S. Environmental Protection Agency primary and secondary drinking water regulations. If *that* is not feasible, the operator must demonstrate to the regulatory agency that leaving the parameter at the higher concentration will not threaten public health and safety, and that, on a parameter-by-parameter basis, water use will not be significantly degraded from its pre-mining condition.

Chemistry of Typical Uranium-Rich Lixiviant

(milligrams/liter unless noted)

calcium	100 - 350
magnesium	10 - 50
sodium	500 - 1600
potassium	25 - 250
carbonate	0 - 500
bicarbonate	800 - 1500
sulfate	100 - 1200
chloride	250 - 1800
silica	25 - 50
total dissolve solids	1500 - 5500
uranium	50 - 250
^{226}radium (pCi/l)	500
conductivity (µS/cm)	2500 - 7500
pH	7 - 9

pCi/l = picoCuries/liter
µS/cm = microsiemens/liter

ISR operations produce small amounts of solid wastes and predominantly liquid effluents. Solid wastes such as contaminated equipment, resin, and pond sediments are generally transported to licensed facilities, and liquid waste from the wellfield, process circuit, and aquifer restoration usually is injected into deep waste disposal wells.

see In-Situ, page 34

Geology, continued from page 21

Solution-collapse breccia pipe uranium deposits occur in the CPUP, particularly in the Grand Canyon region.

The surface disturbance that results from mining this type of deposit historically has been remarkably small because of the high-grade, compact nature of the mineralization and use of underground waste rock backfill techniques during mine development. A 1,000- to 1,600-foot-deep shaft is usually required to access the deposits unless the pipe occurs near a deep canyon.

Breccia pipe ore grades are at least as high as any other global uranium-deposit type, at 0.4 to 1 percent, because the limited size of the pipe concentrates the uranium. Average ore reserves for an individual mineralized pipe are about 3.5 million pounds U_30_8, with an average grade of about 0.6 percent uranium.

Volcanic uranium deposits are found in volcanic and volcaniclastic rocks. Volcanic deposits and hydrothermal veins occur in rhyolitic flows and tuffaceous ash flows, formed by hydrothermal, hot springs, or meteoric waters. Tabular lacustrine sandstone deposits occur in carbonaceous tuffaceous sandstone and mudstones, deposited by cooler groundwaters.

Several major uranium deposits in the RMIBUP occur as veins in metamorphic and sedimentary rocks, primarily within the Front Range and central Rocky Mountains of Colorado. Here, hydrothermal fluids directly deposited the uranium in fracture systems. Most of the BRUP deposits are volcanic, occurring as vein deposits and tabular ore bodies in paleolake sediments associated with volcanic activity. Volcanic deposits generally are developed by conventional mining methods.

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Remediation, continued from page 23

several hundred years. This isn't good news as far as restoring geochemical conditions to premining conditions, but it provides assurance that contaminated groundwater will not migrate and contaminate new areas.

Future Operations

The Grants uranium district still contains several hundred million pounds of uranium, now worth $60 per pound of U_3O_8. This elevated price will only raise interest in renewed mining and milling in the area. Conventional, open pit, and stope leach mining have historically been conducted in the Grants uranium district; all these methods, along with in-situ leaching, may be proposed in the future.

Environmental regulations that were absent during most of the past mining activities are now in place, along with more stringent mining regulations that will protect human health and the environment to a much greater degree. If water produced during new dewatering activities will be discharged to the surface, it will have to be treated to groundwater and possibly drinking-water standards prior to discharge. This will help prevent additional contamination, but water discharged to the surface could remobilize any contamination still present in the soil from the previous operational period if not addressed before new operations begin. This and continued exposure and oxidation of the ore body above the water table will continue to present challenges in managing potential contamination. However, the current regulations include flexibility to require protective engineering controls during operations and adequate financial assurance to address closure requirements.

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In Situ, continued from page 29

Aquifer Impacts?

Before ISR even begins, the uranium ore-bearing aquifer contains naturally occurring ^{226}radium, ^{222}radon, and other uranium-decay products at concentrations exceeding EPA drinking water standards (see table below). Nonpotable water such as this can be exempted as an underground source of drinking water under EPA's Safe Drinking Water Act, and the field of injection and extraction wells can be permitted for Class III underground injection control (UIC) activity. UIC regulations require ISR operations to be designed to produce only from the exempted area, and monitoring must demonstrate that the leach solution is contained within the ore zone. Monitoring parameters are typically chosen that are high in concentration compared to surrounding ambient groundwater, are robust, and may be rapidly analyzed at site laboratories. Parameters such as conductivity, chloride, bicarbonate, sulfate, and uranium are common. Restoration must be completed before monitoring ceases, to prevent regional contamination.

Construction, operation, monitoring, and reporting at ISR sites in the United States have been highly successful in ensuring that leach solution remains confined to the exempted ore zone, as required by UIC regulations. As a result of these practices and the fact that the ore bodies are not in drinking-water-quality aquifers, ISR uranium operations have caused no adverse impact to underground sources of drinking water in the United States.

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Parameter	Average	EPA MCL
uranium (ppb)	488	30
^{226}radium (pCi/l)	215	5.0
^{222}radon (pCi/l)	207,133	300
gross alpha (pCi/l)	865	15

Water quality data from 89 baseline wells, collected prior to initiation of ISR operations, in the mineralized portion of the Oakville aquifer at the URI Inc. Vasquez ISR project in Duval County, Texas. EPA's maximum contaminant levels (MCLs) are shown for comparison.