

Wyoming Mining Association White Paper

Re:
Uranium In-Situ Recovery

In situ mining is a process by which uranium is extracted from porous and permeable host sands via wells completed into those sands. Solutions (called lixiviants) are injected into some wells and recovered from others. During mining the lixiviants pass through the host sand from the injection well (point of entry) to the recovery well (point of removal/exit). It dissolves uranium out of the host sand via a chemical reaction involving oxidation.

Modern uranium extraction by in situ recovery (ISR) is an environmentally benign process that involves minimal surface disturbance, minimal generation of solid wastes and two (2) simple chemicals, carbon dioxide and oxygen.

All operations consist of well fields from which the uranium is extracted, ion exchange plants in which the uranium is loaded onto ion exchange resins and elution/precipitation plants in which the uranium is stripped from the resin and precipitated as uranium oxide (yellowcake).

These facilities are operated under either a Nuclear Regulatory Commission (NRC) source material license, or an agreement state source material license. The operations are also operated under an Environmental Protection Agency aquifer (groundwater) exemption, underground injection control (UIC) permits and state issued permits to mine.

The Figure 1 below provides a flowsheet for the entire process:

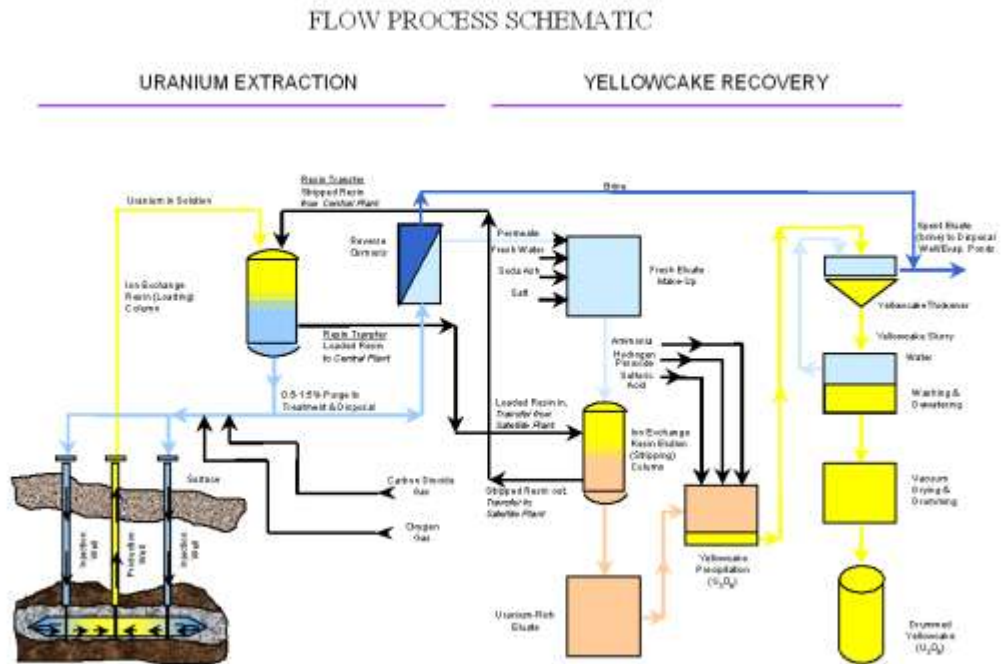


Figure 1 General Process Flowsheet

Process Description

The process is applied to deposits in porous and permeable sands and sandstones, generally to “roll front deposits. A photograph of a typical uranium roll front (Figure 2) compared with a conceptual model of one (Figure 3) is shown below:



Figure 2 – Roll front photograph

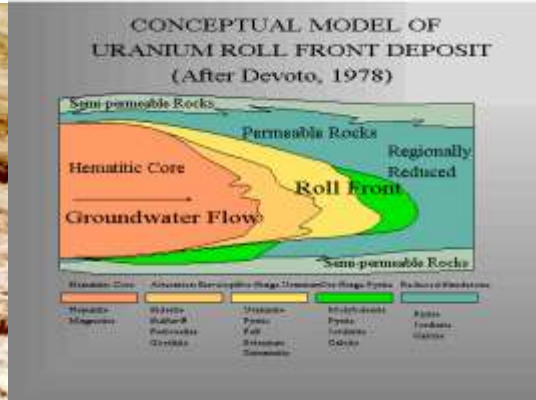


Figure 3 – Conceptual model of a roll front - 1978

A typical in-situ mineable uranium bearing reduced sand is shown in Figure 4 below:



Figure 4 Typical uranium-bearing sand



Figure 5 Drill Rig

Wellfield Installation - Wyoming

The in situ recovery process begins with the completion of wells in the orebody using a large water well rig as shown above right in Figure 5.

A hole is drilled, geophysically logged and cased as is shown above. Most commonly the well is cased with PVC pipe. The area covered with wells is called a well field. The wells are screened (completed) just in the actual ore zone, which is determined by gamma logging of the borehole prior to casing. A diagram of a typical well completion is shown below in Figure 6:

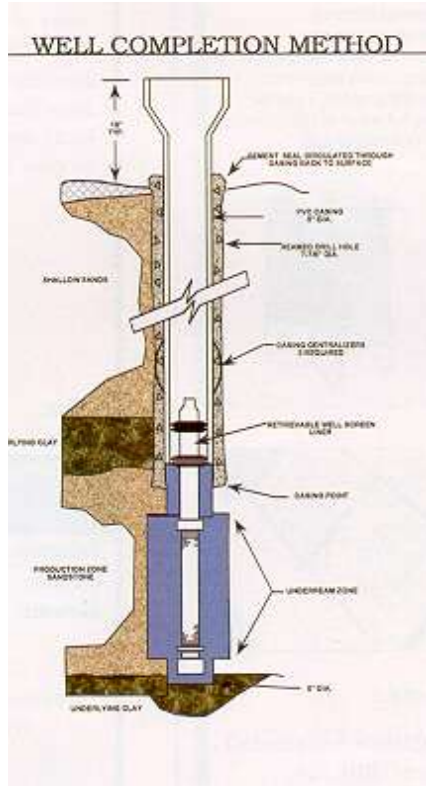
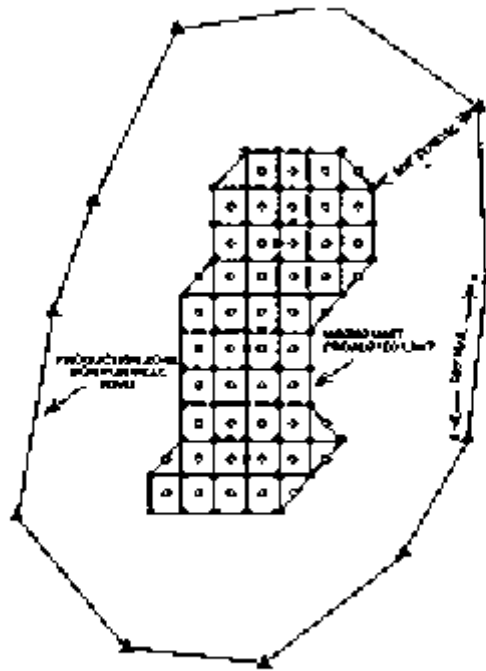


Figure 6 Typical Well completion

This forces fluid injected into the well to only enter the ore zone and forces fluids pumped from the well to only originate from the ore zone. The wells are completed in varying patterns and at different depths, depending upon the shape and depth of the orebody. Generally, wells are approximately fifty (50) to one hundred (100) feet apart. A typical well pattern is shown below:

**TYPICAL WELLFIELD DEVELOPMENT PATTERN
SMITH RANCH PROJECT**



- PRODUCTION WELL
- PRODUCTION MONITOR WELL
- ▲ PRODUCTION MONITOR WELL
- OVERHEAD LAG LAYER MONITOR WELL
- SATURATED LAG LAYER MONITOR WELL

Figure 7 below shows how in-situ uranium recovery wells are completed in a typical roll front deposit and Figure 8 shows how the sandstones are swept by the lixiviant to recover the uranium:

Figure 2
**TYPICAL
 INJECTION & RECOVERY
 WELL COMPLETION INTERVALS**

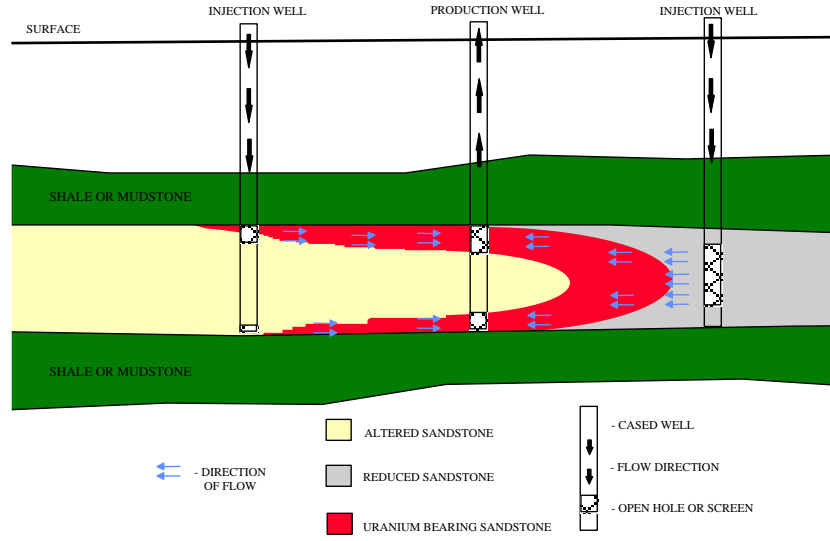


Figure 7 Injection and Recovery in a Rollfront

Typical Five Spot Well Pattern

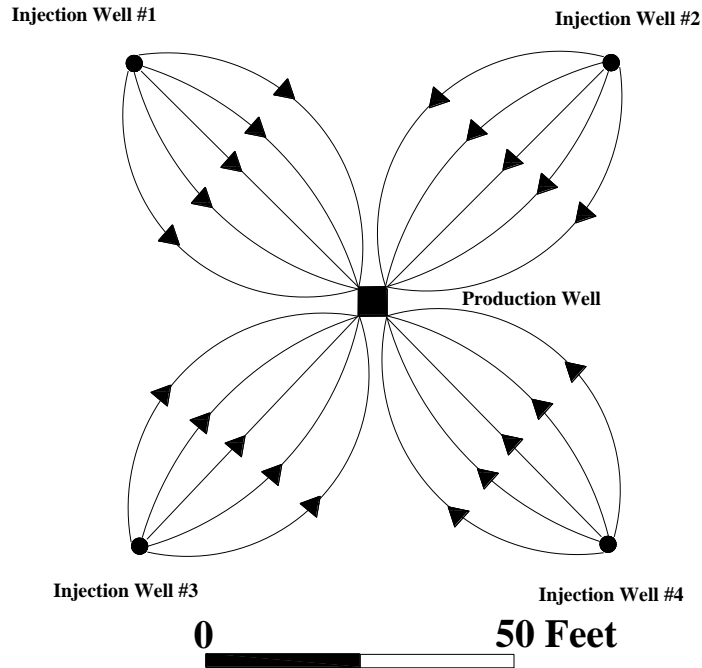


Figure 8 Injection and Production Wells

When the well field has been installed, the injection and production wells connected through pipelines. Figures 9 and 10 below show a typical wellfield:

Mining begins when carbon dioxide (the complexing agent) and oxygen (the oxidant), which are both gasses, are added to groundwater removed from the aquifer. The fluid (groundwater with added carbon dioxide and oxygen) is now called the lixiviant. The lixiviant is injected into the injection wells. The production wells are pumped to recover the lixiviant. As the lixiviant passes through the uranium bearing sands between the injection and production wells, the oxygen oxidizes the uranium in the formation while the carbon dioxide complexes it as soluble uranyl tricarbonate.

Figure 10 shows the general arrangement of an in-situ recovery wellfield while Figure 9 is a photograph of a wellfield.



Figure 9 Wellfield –

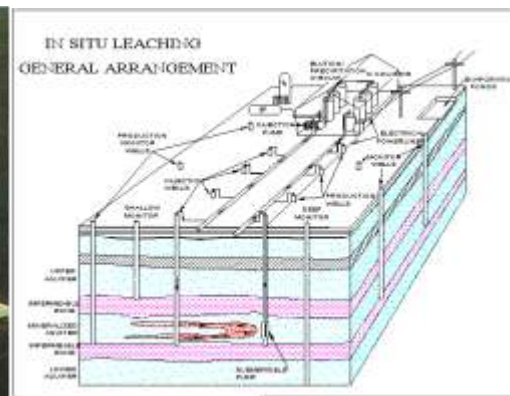


Figure 10 – Wellfield Diagram

The uranium dissolves in the lixiviant and is carried to the production wells where the lixiviant is pumped to the surface via the downhole pumps installed in each production well. The lixiviant is

pumped to an ion exchange plant which functions like a large water softener. Figure 11 is a photograph of an ion exchange plant while Figure 12 is a simplified flowsheet of a satellite recovery plant.



Figure 11 Ion Exchange Columns –

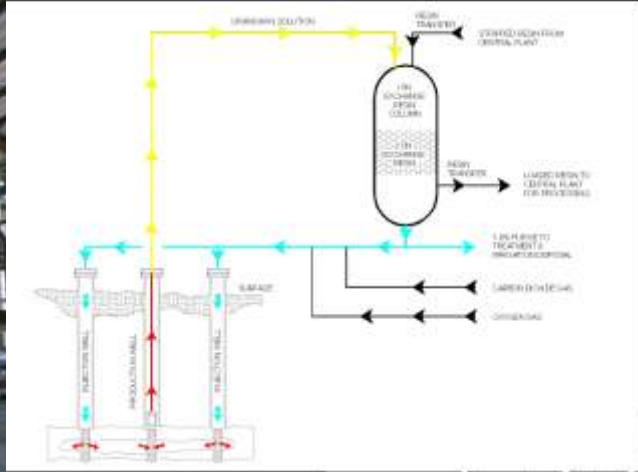


Figure 12 Satellite Plant Flowsheet –

This photograph is of ion exchange columns. A flow sheet for a satellite plant is in Figure 12. This flowsheet describes how any downflow ion exchange columns operate. The lixiviant flows through beads of ion exchange resin contained in an ion exchange column (usually a sealed pressure vessel) which capture the uranium from the lixiviant.

Some times upflow columns are used in which the lixiviant flows up from the bottom of the column through the resin bed and out the top over weirs.

A stand alone ion exchange plant in or near a well field is known as a satellite plant. A satellite plant with a resin-hauling trailer is shown below in Figure 15.



Figure 15 Satellite Ion Exchange Columns with Resin Trailer –

The ion exchange resin will capture approximately six (6) to eight (8) pounds of uranium per cubic foot of resin. Once loaded the resin must be eluted (stripped of its uranium content).

A process called elution removes the uranium loaded on the resin in the columns

- The resin is washed/eluted in place/inside of the columns with a four- (4) normal sodium chloride solution with sodium carbonate added to increase the pH to 9.0 to 9.4.
- The chloride exchanges for the uranium on the resin and the uranium enters the eluate solution. The resin is eluted in several stages using fresher and fresher eluant to insure good removal of the loaded uranium. Usually the resin must be eluted with at least four (4) to eight (8) bed volumes of eluate (depending upon whether the resin is air agitated during the elution process) in four (4) stages to assure complete elution.
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This process is often performed in a central plant. The loaded resin is hauled by truck to a central location for elution. A flowsheet is shown below in Figure 17.

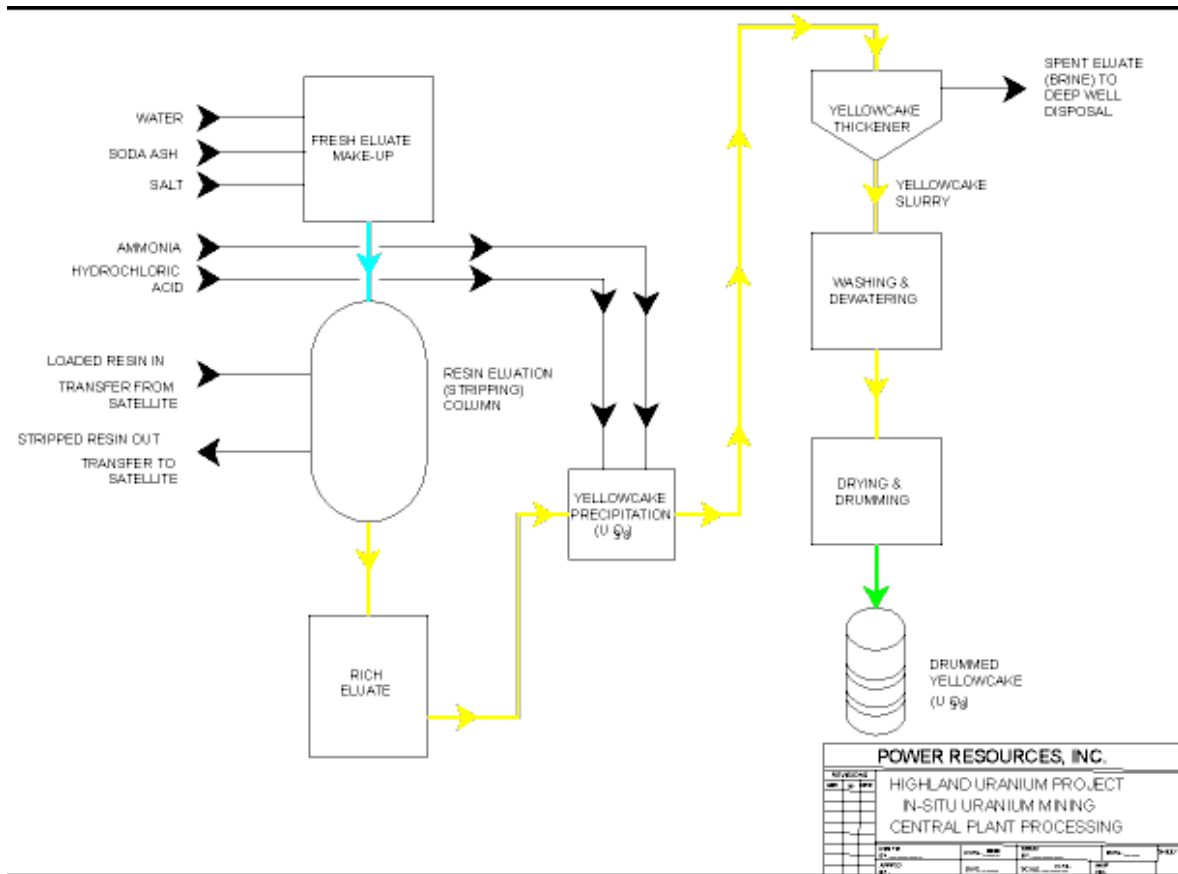


Figure 17 Central Plant Flowsheet

The uranium, now in a concentrated solution, called eluate is precipitated, usually with hydrochloric acid and hydrogen peroxide, but sometimes with ammonia and sulfuric acid. The maximally loaded (pregnant) eluate can be treated to precipitate the dissolved uranium by the following process:

- Hydrochloric acid is added to lower the pH.
- Concentrated (30% to 50%) hydrogen peroxide (H₂O₂) is added at a 0.15 moles H₂O₂ to one (1) mole U₃O₈
- A flocculent is added to settle the yellowcake.
- Precipitation is usually performed in a cone bottomed fiberglass tank
- The pH of the tank's contents is adjusted (raised) with caustic soda to at least four (4) if not five (5) or higher.
- The now settled yellowcake is decanted and pumped into either a thickener or belt filtered prior to drying or pumping into a slurry trailer for haulage to a drying facility.
- Belt filtering of yellowcake slurry is shown below

The uranium is precipitated as slurry called yellowcake shown in Figure 19 below. The yellowcake slurry is dried and barreled and shipped to a converter. Often the slurry is either centrifuged or filter pressed prior to drying to remove excess fluid as is shown in Figure 18 below.



Figure 18 Yellowcake Slurry



Figure 19 Dried Yellowcake Product

Drying is either accomplished with a multiple hearth roaster or via a rotary vacuum dryer.

Ground Water Restoration

Once the uranium has been extracted from the aquifer, elevated quantities of uranium along with some other metals such as selenium, molybdenum and vanadium remain in the ground water. In addition, the total dissolved solids (TDS) content of the ground water may be elevated. The groundwater must be restored in accordance with the permit requirements and applicable State and federal regulations. Ground water restoration can begin by first removing water from the aquifer and disposing of it by evaporation or disposal into a deep injection well which places the water into a deep brine laden formation. The water can also be removed, treated and sprayed on to an irrigation area where it is used to grow a crop - usually hay. This process is shown in Figure 20. An irrigation area is shown in Figure 22. The water can then be further treated with reverse osmosis. Use of this process involves pumping volumes of water out of the aquifer, treating it by concentrating the contaminants into a small bleed stream, which is evaporated or injected into a disposal well, and reinjecting the purified water into the aquifer. This process is depicted in Figure 21. In some cases, the aquifer water can be treated and discharged under an NPDES permit or sprayed on a field to grow a hay crop, a method known as land application. Figure 7 and Figure 8 show Phase I and II of groundwater restoration as performed. In some cases, the aquifer water is treated with a reductant such as hydrogen sulfide to precipitate metals (uranium, selenium, arsenic, and molybdenum) in it. Recently, tests on using bioremediation as a means of groundwater restoration have been performed in the industry. Nutrients are injected in wellfields to be restored and bacteria (native or introduced) metabolize the nutrients and respire on dissolved metals precipitating them. Groundwater restoration methods vary widely by operator.

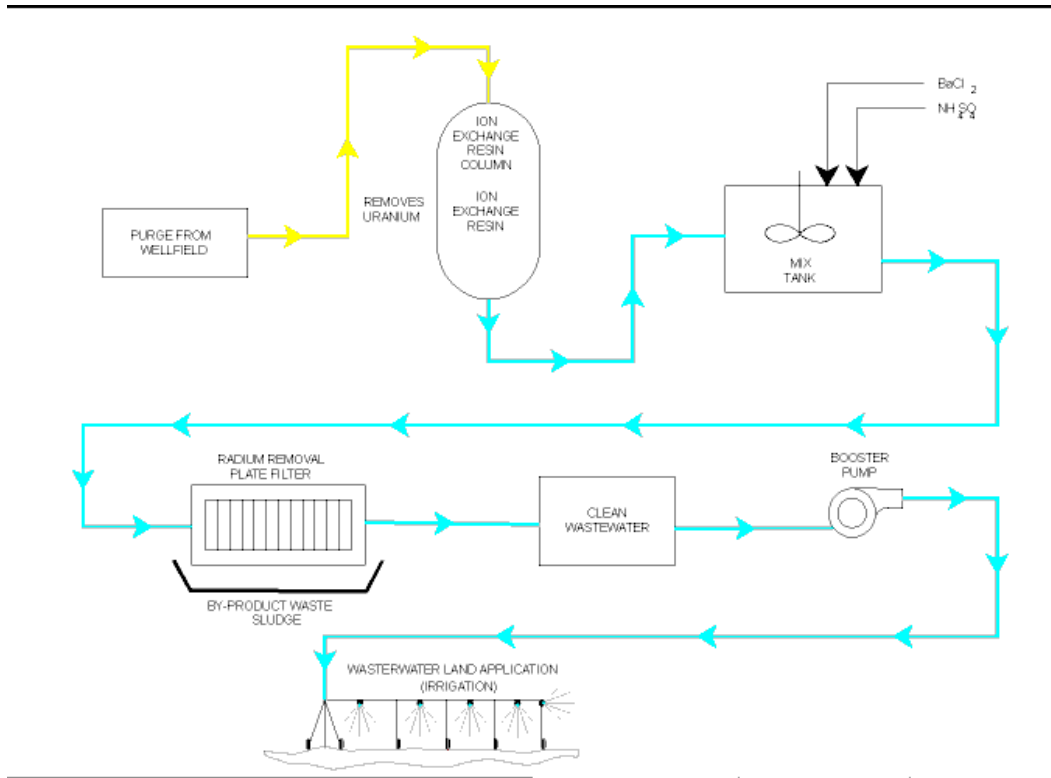


Figure 20 Groundwater Restoration Flowsheet

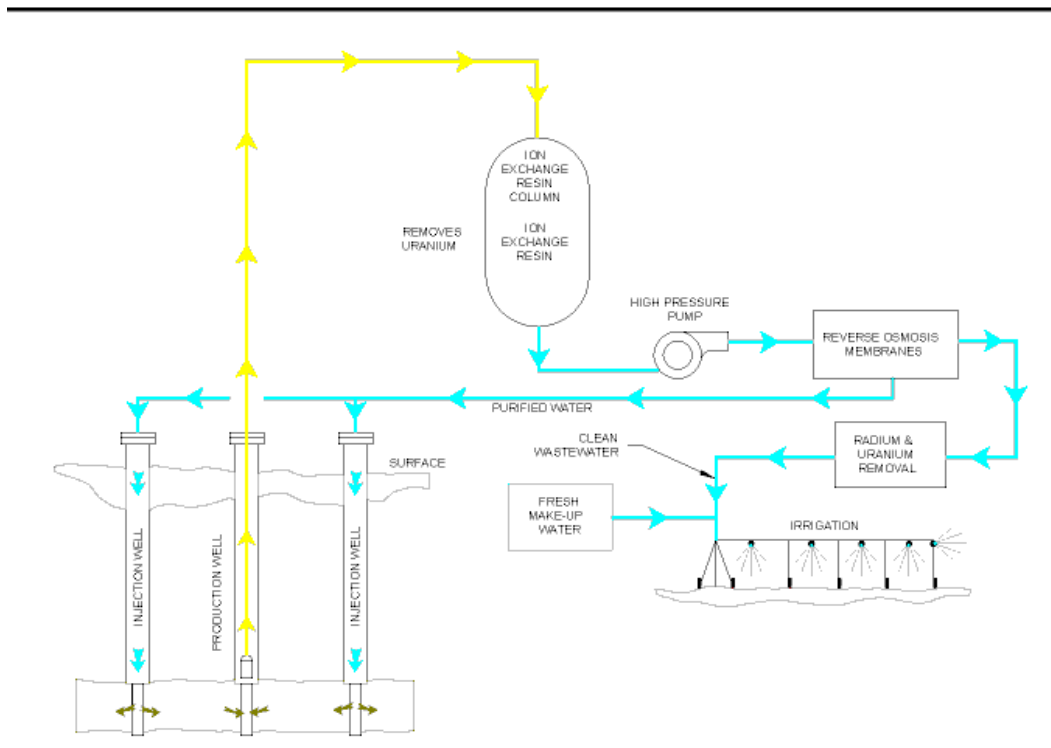


Figure 21 Groundwater Restoration Flowsheet Using Reverse Osmosis



Figure 22 Irrigation Area



The amount of surface disturbance is minimal. The actual extraction process is conducted underground. Most of the uranium is extracted from roll front deposits. An image of a typical roll front is shown below:

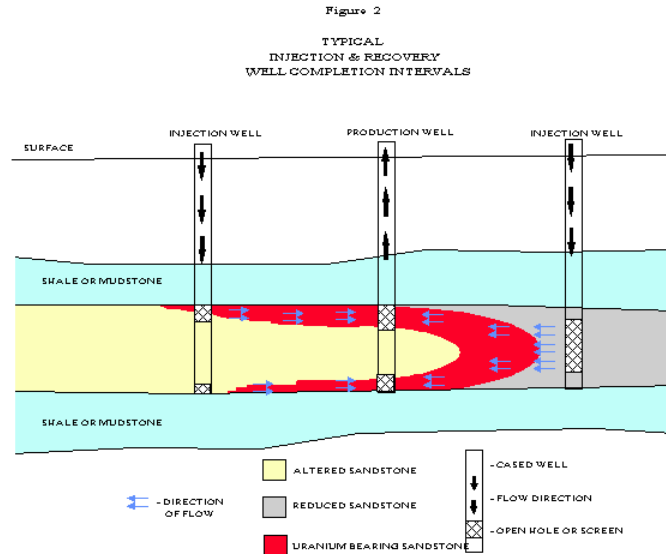
Water Resources

The single largest item regarding in-situ uranium recovery is water resources. In order to perform uranium in-situ mining the deposit must be in the saturated zone of an aquifer unless through extraordinary measures the unsaturated are somehow grouted off from the unmineralized areas and artificially saturated/flooded.

Uranium in-situ recovery operations are conducted within exempted portions of aquifers. Prior to operating, the operator must obtain an aquifer exemption for the portion of the aquifer in which the recovery operations are conducted from the Environmental Protection Agency (EPA) under 40 CFR Part 144. The initial aquifer exemption application is submitted to the State under their applicable regulations and, following State approval, is then submitted by the State to the Environmental Protection Agency (EPA) for final approval. This layer of regulation is an

important piece of regulatory oversight that assures that in-situ uranium recovery operations do not adversely impact groundwater.

As a general rule the process is conducted within the saturated zone of an aquifer between impermeable confining layers that reduce the potential for vertical movement of groundwater as shown in the diagram below:



Monitor wells must be developed above, below and in the producing aquifer. Any elevation of constituents in those monitor wells must be addressed immediately by the operator.

The in-situ uranium recovery process does not result in the consumptive use of groundwater that occurs in open pit or underground uranium mining where large volumes of water are pumped out of an aquifer and discharged.

Positive Benefits of ISR Mining

Ecology

The in-situ uranium recovery process is minimally intrusive with a small surface footprint causing little intrusion into the areas ecology.

Air Quality

In-situ uranium recovery operations have no ore pads or tailings impoundments so there is no associated windblown ore dust or tailings. Many use rotary vacuum dryers, which do not emit particulates. Thus air quality issues associated with in-situ uranium recovery operations are minimal.

Noise

In-situ uranium recovery operations are quiet and located generally in remote areas so they present little associated noise problems. Possibly the greatest source of noise at such an operation are the drill rigs used to install the injection and recovery wells in the wellfield.

Historical and Cultural Resources:

Mining can occur in areas with historical and cultural resources. Because of the low surface footprint of ISR mining, historic resources can be protected.

Visual and Scenic Resources:

In-situ uranium recovery operations do not have major visual impacts.

Socioeconomics

Uranium in-situ recovery operations are not large employers and will not have the socio economic impact of other large industrial activities.

