Groundwater in mine reaching surface due to inadequate backfill

Paguate Reservoir never reclaimed as it was outside mine lease but received 30 years of mine water runoff

Paguate Village resident Larry Esten discusses mine reclamation with NIEHS director Lynne Birnbaum, March 2013.

Dorothy Purley, who drove an orphaned truck at the Jackpile Mine, was a leading advocate for reclamation and health studies prior to her death from cancer in 2003.

Photo showing mine at height of production in 1979.

Jackpile uranium mine, Laguna Pueblo, New Mexico next to Paguate Village listed as a Superfund Site in 2013 due to effort by Pueblo to improve reclamation work conducted in 1986-94.
Best Practice at Uranium Mines and Mills – where is it needed

Energy Production – solar and wind are renewables booming and nuclear reactor growth projections and use are dropping

Reducing demand for new uranium sites and focusing need to apply Best Practices at existing sites to address risk at legacy, “zombie” and operating mines; few if any new mines likely in near future due to falling demand for uranium as nuclear fuel.

Uranium Mill Tailings – Best Practice – Dry Tailings in Below Grade Disposal Sites
  NRC in USA recommends below grade disposal as prime option.
  Mt. Polley Panel in Canada recommends dry tailings and reduced use of water covers

Uranium Mine Waste Rock
  IAEA recommends that uranium mine waste rock be managed similar to uranium tailings because they have similar long-lived radioactive and non-radioactive constituents.

In Situ Recovery – Solution Mining
40CFR192 – restoration and background for ore zone, adjacent portions of aquifer
Uranium Supply and Demand Projections 2015 – 2020

Current excess existing and committed production capacity vs. reactor demand:
- 15,000 – 20,000 tpyU with “high demand”
- 30,000 – 40,000 tpyU with “low demand”

Little if any uranium demand for any new planned and prospective production until 2023 in high demand scenario.
NO demand for new planned and prospective uranium production through end of graph at 2035 with low demand scenario.
Uranium Mill Tailings – Best Practice – Dry Tailings in Below Grade Disposal Sites

Churchrock tailing tailings dam spill among events that led to adoption of US Nuclear Regulation Commission (NRC) regulatory standard since mid-1980s
- “Criterion 3—The "prime option" for disposal of tailings is placement below grade, either in mines or specially excavated pits (that is, where the need for any specially constructed retention structure is eliminated).”

Mt. Polley tailings spill in August 2014 has lead to its first set of recommendations from an Expert Panel that:
“...concluded that the future requires not only an improved adoption of best applicable practices (BAP), but also a migration to best available technology (BAT). Examples of BAT are filtered, unsaturated, compacted tailings and reduction in the use of water covers in a closure setting. Examples of BAP bear on improvements in corporate design responsibilities, and adoption of Independent Tailings Review Boards.” Mt. Polley Independent Expert Panel Report, Exec Summary p. 8/156

KEY DESIGN AND OPERATION CRITERIA
- Below-grade disposal requires all tailings material to be below original land surface (“grade”)
- Filtered, unsaturated, compacted tailings possible using existing technology to produce high-density thickened, paste or dry tailings
- Reduction of use of water covers in a closure setting.
Puerco River Contaminant Source:
Church Rock Uranium Mill Tailings Spill,* July 16, 1979
*Largest release of radioactive wastes, by volume, in US history

United Nuclear Corp. Uranium Mill Tailings Dam, July 16, 1979

Dam breach location, July 17, 1979

WARNING
ALL USE OF WATER FROM THIS AREA IS DISCOURAGED BY THE N.M.E.I.D.
AVISOS
N.M.E.I.D. NO RECOMIENDA EL USO DE AGUA DE ESTE RÍO.
BAHA DZID
N.M.E.I.D. NO USO

Puerco River warning sign

NMEID Sampling in Puerco R. after spill

Livestock tracks in Puerco River downstream of spill, July 17, 1979

Community leaders Larry J. King (L) and Robinson Kelly addressed long-term impacts of spill in 2009.

Photos courtesy of Southwest Research and Information Center, New Mexico Environmental Improvement Division, Albuquerque Journal.
Mt. Polley Tailings Dam Failure and Spill


http://www.miningwatch.ca/blog/mount-polley-and-failure-compliance

July 29, 2014

http://commonsensecanadian.ca/mount-polley-spill-may-far-bigger-initially-revealed/

August 5, 2014

Below–grade disposal is being used for the Moab (Utah) Tailings Relocation Project that is excavating and transporting a 16,000,000-ton inactive tailings pile to a below grade disposal site 30 km north. Images show: 1) Atlas tailings pile before project began 2) tailings removal in progress, and 3) view after additional tailings removal.

Crescent Junction Disposal Site uses below-grade tailings disposal with windborne particles releases controlled daily cover using material excavated to allow below grade disposal.

From: [http://www.gjem.energy.gov/moab/](http://www.gjem.energy.gov/moab/)
“Mostly” below-grade tailings disposal in phased, lined cells designed for Pinon Ridge Uranium Mill proposed in Colorado

Below-grade disposal proposed for uranium mill tailings disposal for Pena Ranch mill, New Mexico (from design provided to NRC, permit application proposed but not filed)
High Density Thickened Tailings (HDTT) Storage
- Thickened tailings, as the name suggests, involves the mechanical process of dewatering low solids concentrated slurry. This is normally achieved by using compression (or high rate) thickeners or a combination of thickeners and filter presses. High Density Thickened Tailings (HDTT) are defined as tailings that have been significantly dewatered to a point where they will form a homogeneous non-segregated mass when deposited from the end of a pipe.

Surface Paste Tailings Disposal
Paste tailings are defined as tailings that have been significantly dewatered to a point where they do not have a critical flow velocity when pumped, do not segregate as they deposit and produce minimal (if any) bleed water when discharged from a pipe.

Dry Stacking of Tailings (Filtered Tailings)
- Dewatering tailings to higher degrees than paste produces a filtered wet (saturated) and dry (unsaturated) cake that can no longer be transported by pipeline due to its low moisture content.
Illustrations for Understanding Tailings Dewatering Options

Tailings flow properties

<table>
<thead>
<tr>
<th>Segregates on deposition</th>
<th>Non-segregating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Freshly settled&quot; concentration</td>
<td>No bleed</td>
</tr>
</tbody>
</table>

Un-thickened Tailings | Thickened Tailings | Paste | Cake

<table>
<thead>
<tr>
<th>Fully sheared yield stress</th>
<th>8 kPa to 20 kPa</th>
<th>100 Pa</th>
<th>500 Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Ore Tailings</td>
<td>64 Pa</td>
<td>100 Pa</td>
<td></td>
</tr>
<tr>
<td>Ketchup</td>
<td>15 Pa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cost vs Benefit to Recover Tailings Water

Where is the best investment in water recovery from tailings for the least cost?


SLURRY RHEOLOGY VS. WT % SOLIDS

http://technology.infomine.com/reviews/PasteTailings/

Canadian Nuclear Safety Commission (CNSC) Review of Canadian uranium mill tailings sites

Started announced shortly after Mt. Polley spill. No information available yet on how the Independent Panel Recommendations to reduce use of water covers for closure situations to be applied at Elliot Lake, Ontario, Canada uranium mill tailings sites where permanent water covers have been in place for 20 years at 5 sites containing more than 145 million tons of the more than 160 million tons of uranium mill tailings in the Serpent River watershed.

<table>
<thead>
<tr>
<th>Site</th>
<th>Total Amount of Tailings (M tonnes)</th>
<th>Total Surface Area (ha)</th>
<th>Year of Complete Submersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denison</td>
<td>63</td>
<td>271</td>
<td>1996</td>
</tr>
<tr>
<td>Quirke</td>
<td>46</td>
<td>192</td>
<td>1995</td>
</tr>
<tr>
<td>Panel</td>
<td>16</td>
<td>123</td>
<td>1993</td>
</tr>
<tr>
<td>Spanish-American</td>
<td>0.5</td>
<td>51</td>
<td>1994</td>
</tr>
<tr>
<td>Stanleigh</td>
<td>19.8</td>
<td>411</td>
<td>2002</td>
</tr>
</tbody>
</table>

Sources:
- [http://www.ceaacee.gc.ca/DBD6667F-9B4F-4FB6-A55F-3BBD1D8C5AF3/elliot_e.pdf](http://www.ceaacee.gc.ca/DBD6667F-9B4F-4FB6-A55F-3BBD1D8C5AF3/elliot_e.pdf)
Denison tailings – 63 million tons - are placed in preexisting lakes with man-made perimeter dams.

Quirke – 46 million tons – tailings surrounded by man-made dams and internal dykes with built on tailings, with inflowing water cover water at 5 elevations.

Extensive of water covers in closure setting in Canadian uranium sector. Canadian regulators have allowed water covers at Elliot Lake and in Saskatchewan.
Uranium Mine Waste Rock requires Management similar to tailings

International Atomic Energy Agency (IAEA) has determined that uranium mine waste rock and uranium mill tailings both require similar management systems as both are radioactive waste containing sources of risk including long-lived radioisotopes and heavy metals.

“[S] since mine and mill tailings will continue to present a potential hazard to human health after closure, additional analyses and measures may be needed to provide for the protection of future generations. Such measures should not be left until closure but should be considered and implemented throughout the design, construction and operation of the mining and milling facilities. The protection of the public, from the beginning of operations to post-closure, should be considered in its entirety from the beginning of the design of the facilities. The overall objective and subsidiary criteria developed explicitly for the management of radioactive waste should be consistent with these considerations.”


Midnite Uranium Mine Superfund Site, Spokane Indian Reservation, Washington State

33 million tons of waste rock and 2.4 million tons of uneconomic low grade ore left at mine site required remediation. 2.9 million tons of ore at 0.2% uranium removed to produce 11 million pounds of uranium.

http://www.epa.gov/superfund/sites/npl/nar1546.htm
Midnite Mine remediation cost of $193 million shared by Newmont Mine (72%) and US Government (28%). Completion of Remedial Plan due 2025, perpetual treatment of 5 – 10 million gallons of mine pit and seepage water at on-site plant requires treatment plant with 26 million gallons/year to manage peak flows and disposal site for 40-80 tons of mine water treatment sludge required.

McClean Lake Complex – Sue Site
70% Areva; 22.5% Denison; 7.5% OURD, Ltd.
23,000 t U produced from Sue Site Mines; Reserves 8,000 t U in ore at 2.2% U; No mines current operating – www.denisonmines.com

Mine Waste Dumps remain on surface at Saskatchewan uranium mines. Mines used for tailings disposal in which open pit mines are backfilled with tailings to be covered by water with drainage “blanket” to collect seepage from surrounding rock for treatment and discharge to watershed. Implication of implementing Mt. Polly recommendations regarding “reduction of use of water covers in closure setting” yet to be addressed for mine waste and tailings at Saskatchewan mines.
Collins Bay Mines at Rabbit Lake Complex – 100% Cameco; 91,500 t U – Historical Production – 1975 – 2010; Reserves at remaining deposits at Collins Bay and Eagle Point – 12,750 t U in ore at 0.75% U  www.cameco.com
Mine Waste remediation requires extensive characterization as the large volume of mine wastes - 3 - 5 + times volume of ore for open pits and 50-100% of volume of ore from underground mines - and their storage locations are less well understood than tailings geochemistry and disposal sites.

At Tachee-Blue Gap Chapter of Navajo Nation, 2014 analyses of rocks used as cover over an abandoned uranium mine – “Claim 28” mine shown below - found uranium content of the waste rock cover similar to local ores – 0.2 – 0.7% uranium, 0.4 – 1.5% vanadium – in first samples since the 1990 placement of the “safety” cover. Seeps and springs near the mine topped uranium drinking water standards.

Spring and Seep Water Analyses

<table>
<thead>
<tr>
<th>Sample</th>
<th>Parameter</th>
<th>U (µg/L)</th>
<th>As (µg/L)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td></td>
<td>163</td>
<td>5.7</td>
<td>7.4</td>
</tr>
<tr>
<td>Seep</td>
<td></td>
<td>135</td>
<td>9.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

MCL 30  10

“Claim 28” Mine Waste Analyses

<table>
<thead>
<tr>
<th>Elemental Content, µg g⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>Undisturbed Soil</td>
</tr>
<tr>
<td>Mine waste1</td>
</tr>
<tr>
<td>Mine waste2</td>
</tr>
</tbody>
</table>

The proposed rule would:

- **require ISR operators to monitor ground water for 30 years after demonstrating that the ground water chemistry has been restored and is stable.** Under this proposal, the 30-year monitoring period could be shortened if monitoring data and geochemical modeling show that the ground water chemistry has been restored, has remained stable for at least three consecutive years, and is likely to remain stable into the future. Statistical analyses would have to demonstrate ground water stability at a confidence level of 95 percent.

**Require characterization of background ground water chemistry for ore zone, and adjacent aquifer:** The proposed rule describes how ISR facilities are to characterize ground water chemistry before beginning uranium recovery operations.

**Requirements to meet restoration goals for 13 constituents:** The proposed rule would require compliance with whichever standard is most protective from the US Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), or UMTRCA for each of 13 ground water constituents. The 13 ground water constituents are: arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, nitrate (as nitrogen), molybdenum, radium, total uranium and gross alpha particle activity. If the water in the aquifer meets the ground water standards before ISR operations begin, it would have to be restored to meet them again after operations have stopped. If the constituent concentrations already exceed standards before operations begin, the operator would have to restore the ground water chemistry to original, pre-operational concentrations. If background concentrations or ground water protection standards cannot be achieved, ISR operators can request an Alternate Concentration Limit (ACL), provided that they meet certain criteria and conditions.
**Solution mining**

**Extraction**
A solution of groundwater and oxygen is pumped into injection wells drilled through layers of sandstone. Oxygen rusts uranium in the sandstone. Uranium dissolves in the water, and the solution is pumped to the surface.

**Processing**
The solution is pumped to a plant, where uranium is removed. Water is reoxygenated and pumped back down injection wells. It recirculates until uranium in the deposit is depleted.

**Waste management**
Wastewater is treated and pumped into disposal wells, evaporated or sprinkled into the soil at the surface. Solids are sent to a waste disposal site.

**Restoration**
Water is purified and reinjected into the well field. Wells are later filled with concrete and capped below the surface. Surface soil is decontaminated if necessary.

**Advantages**
- Minimal surface disturbance.
- No mine to rehabilitate.
- Does not create excess rock piles or tailings from processing.
- Can be used for small deposits that are not economical for conventional mining.
- Uranium can be processed on site.
- Less time is needed for establishing and maintaining mining facilities.

**Disadvantages**
- Cannot be used at sites without the necessary geological layering.
- Requires water in the uranium deposit.
- Rock being mined must be permeable.
- Restoring water to an acceptable level of purity can be difficult.

**Sources:**
- Graphics reportina by Tom Reinken; Graphic by Lorena Iniguez Los Angeles Times
Kingsville Dome ISL Mine, Texas
http://www.hanthony.com/aes/Projects/KVD.htm
Figure 3. Schematic of idealized Wyoming Basin uranium roll front deposit showing alteration zones, related mineral components, solution components, and important aqueous chemical reactions for Fe, S, O, and CO\textsubscript{2} (after Granger and Warren, 1974).

Figure 5. Concentration and distribution of uranium in various roll front deposits (after Harshman, 1974).
Cameco-Owned Crow Butte In Situ Uranium Mine, Nebraska

THE COUNCIL TREE

In September 1875 a lone cottonwood provided a landmark where the Allison Commission met with thousands of Lakota Sioux in a futile effort to buy the Black Hills. Based on the recollections of elderly Lakotas, Captain Christopher Robinson Chapter, D.A.R., of Crawford, marked what was believed to be the historic tree in May 1932. The cottonwood, sometimes called "the treaty tree," died in the 1970s. It stood a few hundred feet south of this marker, looking toward Crow Butte.
Figure 6. Concentration and distribution of selenium in various uranium roll front deposits (after Harshman, 1974).

Figure 8. Concentration and distribution of arsenic in various uranium roll front deposits (after Harshman, 1974).
Why is restoration to pre-mining background is so difficult at ISR Mine?:

Consideration of Geochemical Issues in Groundwater Restoration at Uranium In Situ Leach Mining Facilities, NUREG/CR-6870, January 2007
Prepared by USGS for NRC,

...Because of heterogeneities in the aquifers, the fresh groundwater that is brought into the ore zone does not completely displace the residual lixiviant....

...groundwater sweep may cause oxic groundwater from upgradient of the deposit to enter into the mined area, making it more difficult to re-establish chemically reducing conditions...

...it is difficult to predict how much time is required or even if the reducing conditions will return via natural processes. The mining disturbance introduces a considerable amount of oxidant to the mined region.....

Injection of lixiviant - leaching fluid - destroys water quality
  oxidizes & mobilizes contaminants
  changes the redox potential of the rock

Restoration to baseline is not possible as contaminants continue to bleed with time

‘Restored’ water migrates downgradient and follows paleochannel flow paths carrying elevated levels of U, Ra, SO₄, O₂

Natural attenuation is unlikely because the net charge on rock particles is negative therefore anions will not adsorb to rock particle contamination plume grows with time.
Thank you for your time and attention