Best Practices for Uranium Mines and Mills: Where are they needed?

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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

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:

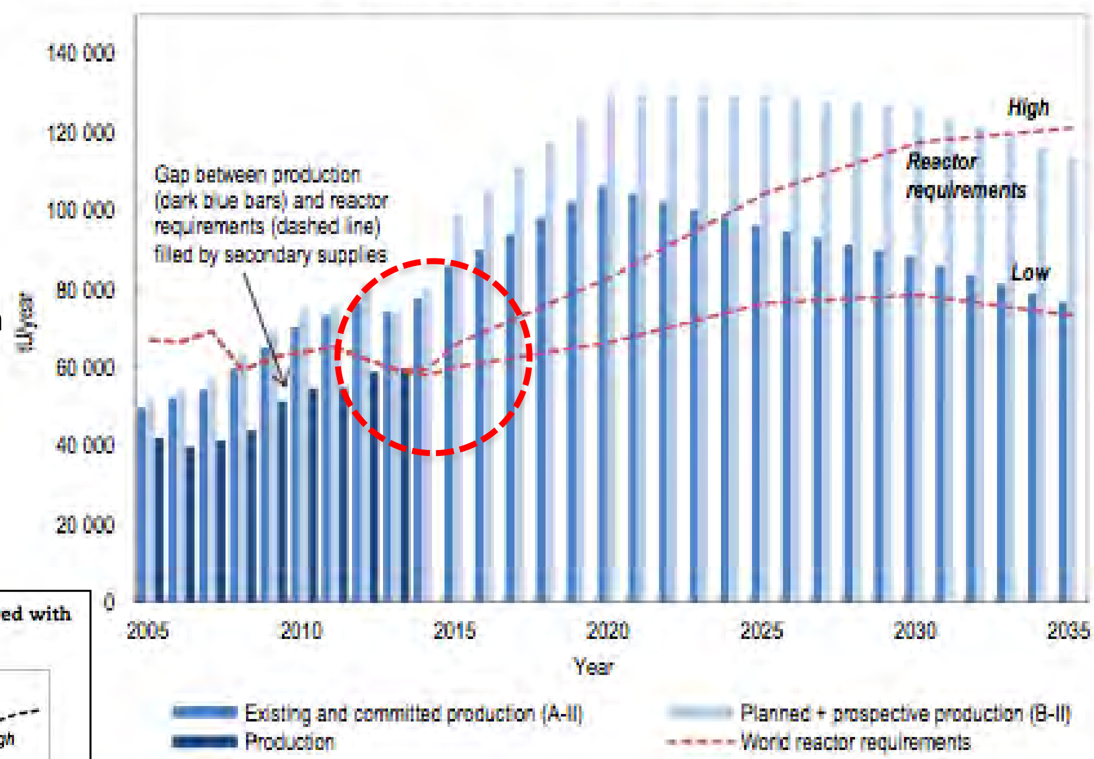
- 15,000 – 20,000 tpyU with "high demand"
- 30,000 – 40,000 tpyU with "low demand"

URedbook2014

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.

Figure 2.11. Projected annual world uranium production capability to 2035 compared with projected world reactor requirements*

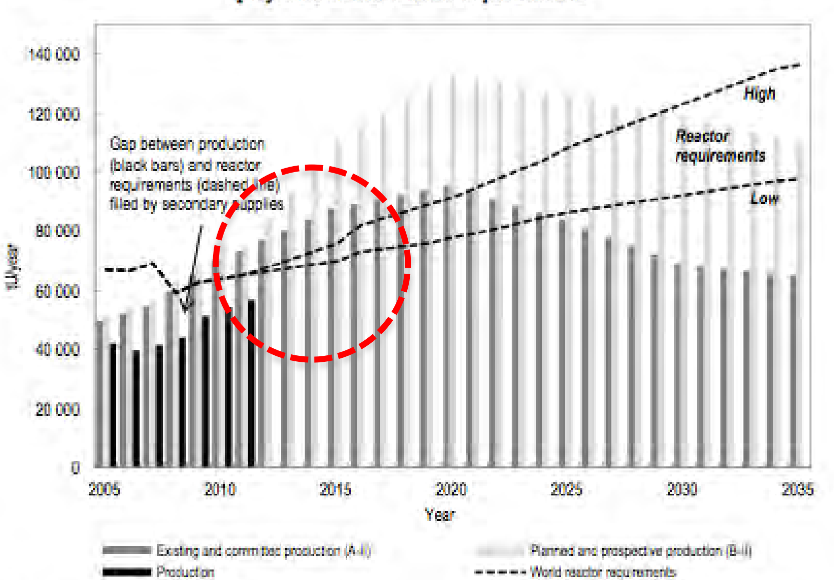


Tables 1.26 and 2.4.

des all existing, committed, planned and prospective production centres supported by RAR and inferred urces recoverable at a cost of <USD 130/kgU.

Uranium Red Book 2014

Figure 2.11. Projected annual world uranium production capability to 2035 compared with projected world reactor requirements*



Source: Tables 2.2 and 2.4.

* Includes all existing, committed, planned and prospective production centres supported by RAR and inferred resources recoverable at a cost of <USD 130/kgU.

Uranium Red Book 2012

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). "

http://www.nrc.gov/reading-rm/doc-collections/cfr/part040/part040-appa.html

10CFR40-Appendix A

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

https://www.mountpolleyreviewpanel.ca/sites/default/files/report/ReportonMountPolleyTailingsStorageFacilityBreach.pdf

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.

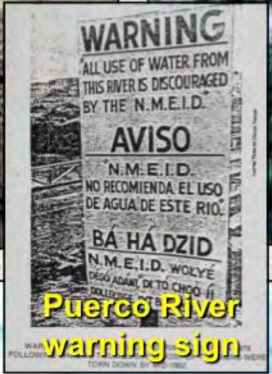
Puerco River Contaminant Source:

Church Rock Uranium Mill Tailings Spill,* July 16, 1979

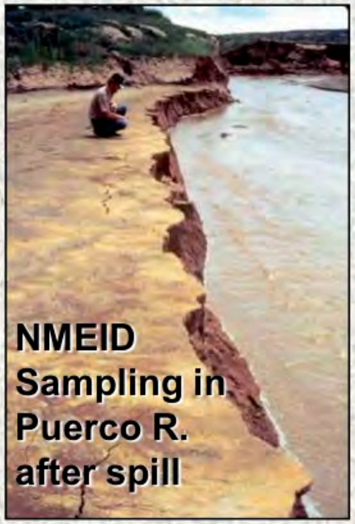
***Largest release of radioactive wastes, by volume, in US history**

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

Dam breach location, July 17, 1979



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.cbc.ca/news/canada/british-columbia/mount-polley-spill-blamed-on-design-of-embankment-1.2937387

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

July 29, 2014 August 5, 2014

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

http://juneauempire.com/local/2014-08-08/advocates-tailings-dam-breach-warning-alaska

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

From: http://www.gjem.energy.gov/moab/
and http://www.moabtailings.org/

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/

"Mostly" below-grade tailings disposal in phased, lined cells designed for Pinon Ridge Uranium Mill proposed in Colorado

Source:"Uranium Tailings Facility Design and Permitting in the Modern Regulatory Environment"http://www.infomine.com/library/publications/docs/Morrison2008.pdf

The Piñon Ridge Project

- Design milling capacity of 500 tons per day, with expansion capacity to 1000 tons per day
- Major mill components:
  - Process plant
  - Tailings cells
  - Evaporation ponds
  - Ore stockpile pads
- Design mill life up to 40 years

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Tailings Cell Design Concepts

- Three tailings cells, constructed in phases
  - Each cell with capacity for 13.4 years at 500 tpd operations
  - Mostly below-grade disposal, with excess cut to be used for closure cover and other site construction
  - 3H:1V internal slopes with intermediate benches
  - 10H:1V external slopes to achieve closure requirements
  - 1% minimum slope at base

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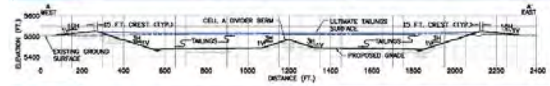
Tailings Cell Design Concepts, cont.



- Tailings Cell A designed as a split cell for contingency purposes
  - For instance, cell A1 could be decommissioned and repaired without disrupting operations
- Tailings Cells B and C are designed as single cells with option for split cell construction

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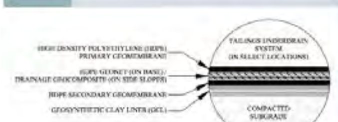
Tailings Cell Liner System Design

- Prescriptive Liner System (40 CFR 264.221) (top to bottom):
  - Primary geomembrane
  - Leak detection layer (drainage gravel or geosynthetic)
  - Secondary geomembrane
  - 3 feet of 10^{-7} cm/sec clay
- Proposed Liner System (top to bottom):
  - 60 mil HDPE primary geomembrane
  - Leak detection system layer with geonet (on base) and drainage geocomposite (on slopes)
  - 60 mil HDPE secondary geomembrane
  - Geosynthetic clay liner (GCL)



Primary Liner Characteristics

- HDPE geomembrane chosen for its long term performance due to:
  - Chemical resistance properties
  - Resistance to UV radiation
  - High tensile strength
  - High stress-crack resistance
- Light-reflective upper surface (i.e., white)
  - Additional UV resistance through UV reflection
  - Minimizes expansion/contraction wrinkles
  - Reduces heat build up and thermal expansion by reflective solar radiation
  - Reduces desiccation effects to subgrade soils
  - Improves visual detection of installation damage
- Conductive liner
  - More reliable quality assurance through spark testing

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Leak Detection System Layer

- Designed per 40 CFR 264.221 to minimize hydraulic head on lower geomembrane liner
  - Leaks through primary liner collected in the LDS layer and routed to a sump
  - Automated submersible pump recovers leak solutions and returns them to the tailings cell
- Leak Detection System (LDS) layer comprised of:
  - HDPE geonet on base of tailings cells
    - High transmissivity
    - Low shear strength in contact with geomembrane, so used only on base of cells
  - Drainage geocomposite on side slopes of cells
    - HDPE geonet laminated on both sides to nonwoven geotextile filtration media
    - Increased interface shear strength for use on side slopes, but decreased transmissivity

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Secondary Composite Liner System

- Designed to maximize the amount of solution recovered by the LDS, and act as a final flow barrier protecting the subgrade
- Design consists of:
  - 60 mil HDPE double-sided textured geomembrane
    - Resistance to chemicals in solution
    - Double-sided texturing to increase frictional resistance
  - Geosynthetic clay liner (GCL)
    - No locally-available sources of clay, and difficult to achieve requirements even by amending local soils with bentonite
    - Compatibility testing with anticipated tailings solution indicate negligible change in GCL permeability
- Analyses (Giroud et al. 1997) show that the proposed secondary liner system with GCL is more stringent than the prescriptive liner system with 3 feet of clay.

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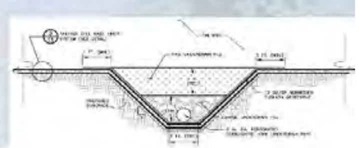
Underdrain System Design

- Underdrain system required to facilitate dewatering of the tailings (6 CCR 1007-1, Part 18, Appendix A, Criterion 5E)
  - Reduce driving head for seepage on the liner system
  - Anticipated tailings gradation is considered amenable to dewatering (i.e., relatively coarse-grained silty sands and sandy silts)
- Design consists of:
  - Perforated HDPE collection pipes at the base of the tailings cell to collect and convey solution to the underdrain sumps
  - Solution collected in underdrain sumps will be returned to the mill circuit through use of automated submersible pumps



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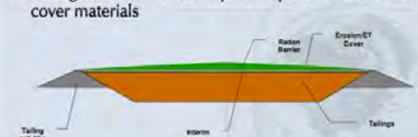
Tailings Closure Considerations

- Minimize post-closure maintenance
- Perimeter external berm side slopes designed at 10H:1V to consider closure
- Cover materials will be placed over tailings in each cell as deposition is complete
- Tailings will be dewatered prior to placement of closure cover materials



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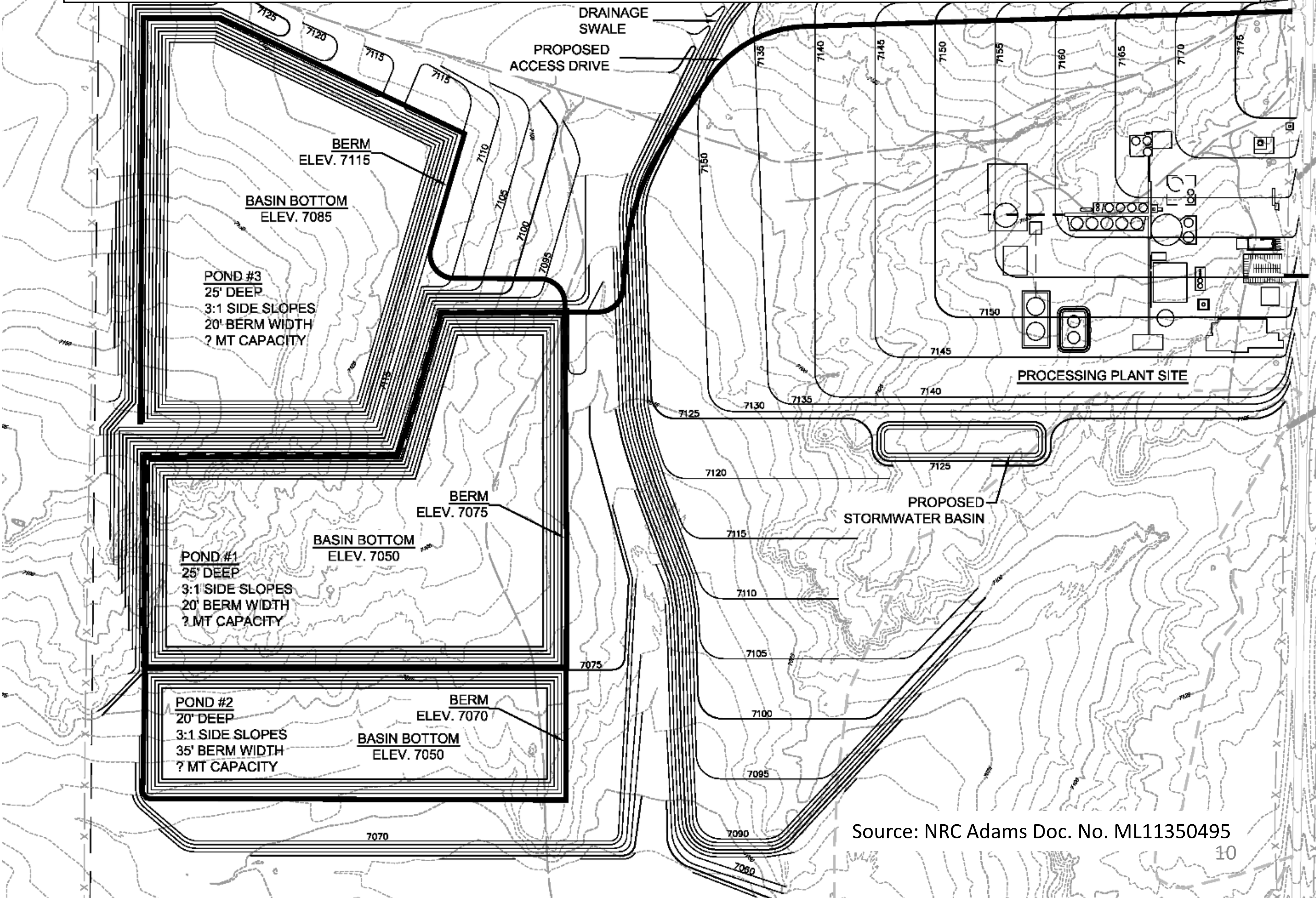
Below-grade disposal proposed for uranium mill tailings disposal for Pena Ranch mill, New Mexico (from design provided to NRC, permit application proposed but not filed)



Source: NRC Adams Doc. No. ML11350495

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

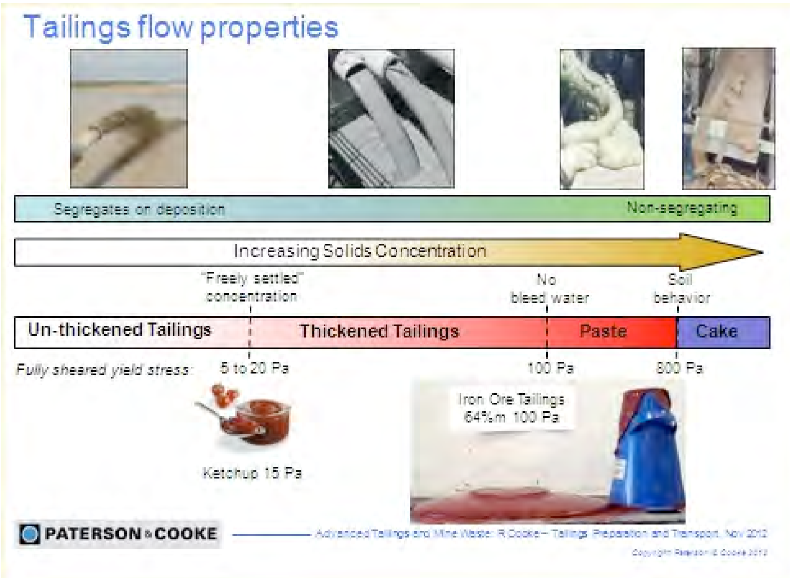
Surface Paste Tailings Disposal

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

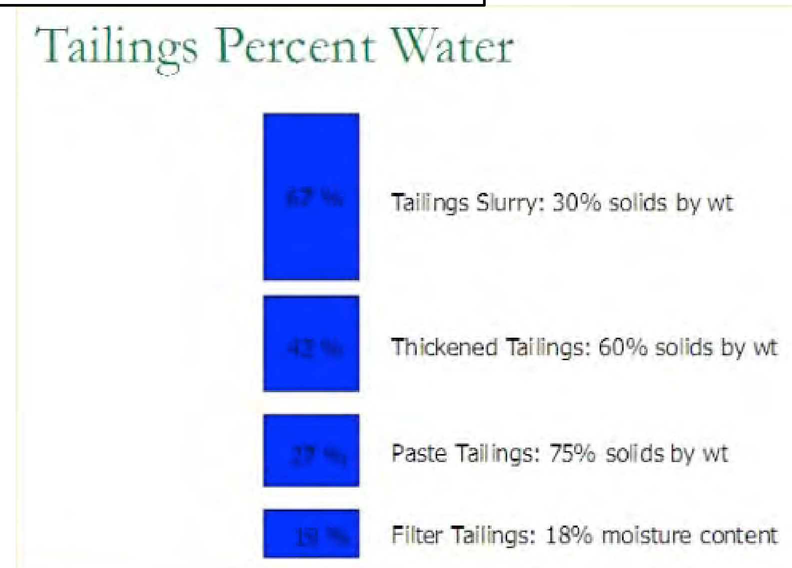
Dry Stacking of Tailings (Filtered Tailings)

- 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



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



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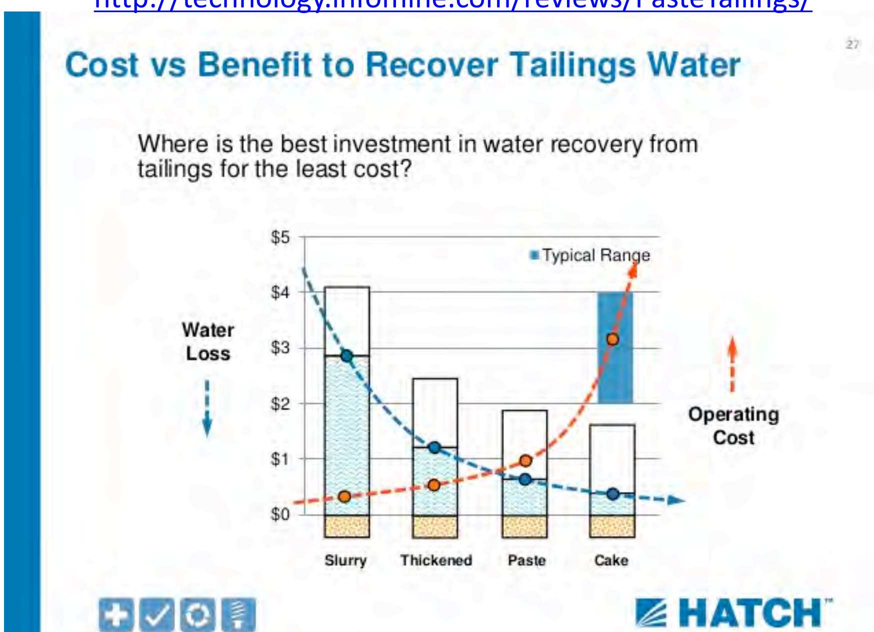
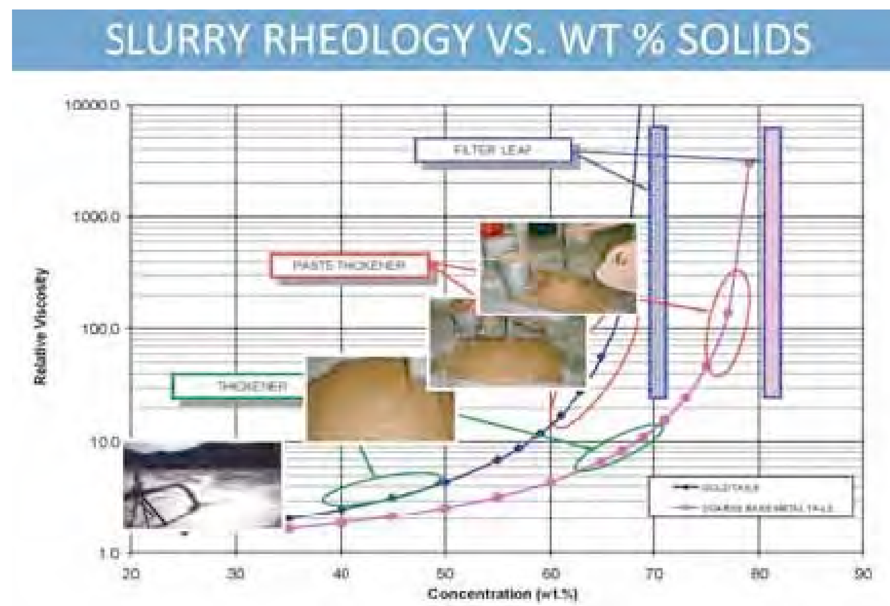


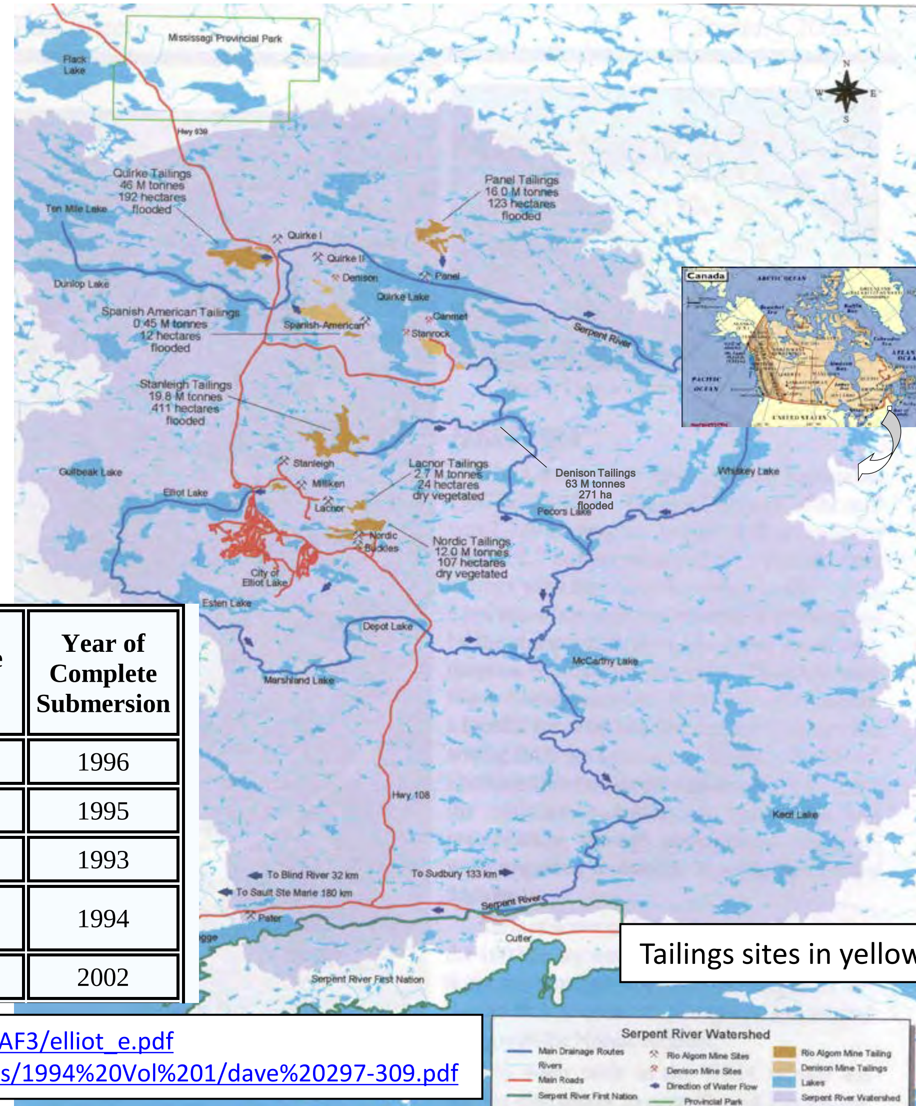
http://www.convencionminera.com/perumin31/encuentros/tecnologia/jueves19/1230-Jerry-Rowe.pdf



http://www.womp-int.com/story/2011vol09/story025.htm

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

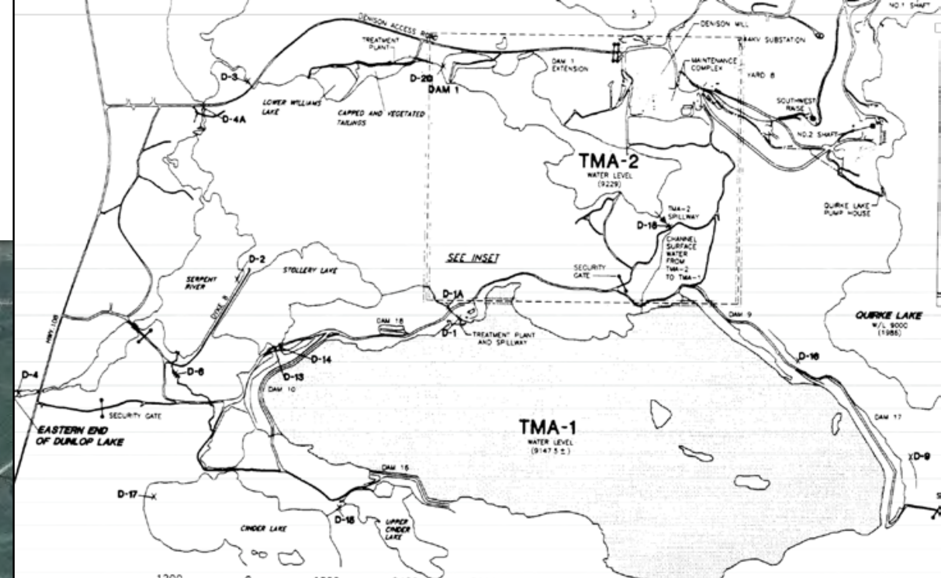
Site	Total Amount of Tailings (M tonnes)	Total Surface Area (ha)	Year of Complete Submersion
Denison	63	271	1996
Quirke	46	192	1995
Panel	16	123	1993
Spanish-American	0.5	51	1994
Stanleigh	19.8	411	2002



Tailings sites in yellow

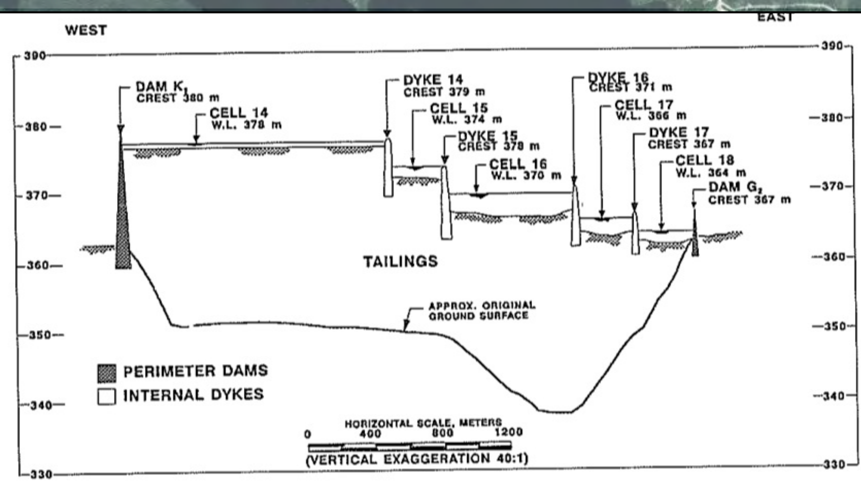
Sources: http://www.ceaa-acee.gc.ca/DBD6667F-9B4F-4FB6-A55F-3BBD1D8C5AF3/elliot_e.pdf
http://www.asmr.us/Publications/Conference%20Proceedings/1994%20Vol%201/dave%20297-309.pdf

Extensive of water covers in closure setting in Canadian uranium sector. Canadian regulators have allowed water covers at Elliot Lake and in Saskatchewan.



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.



Schematic profile of flooding concept, Quirke mine waste management area.

Uranium Mine Waste Rock requires Management similar to tailings

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.

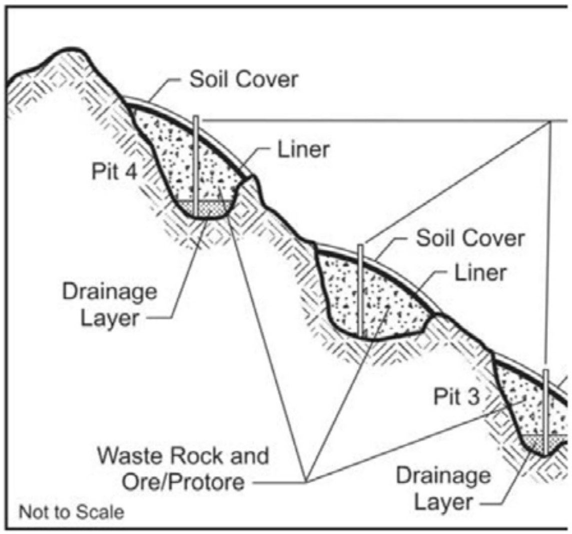
http://www.epa.gov/superfund/sites/npl/nar1546.htm

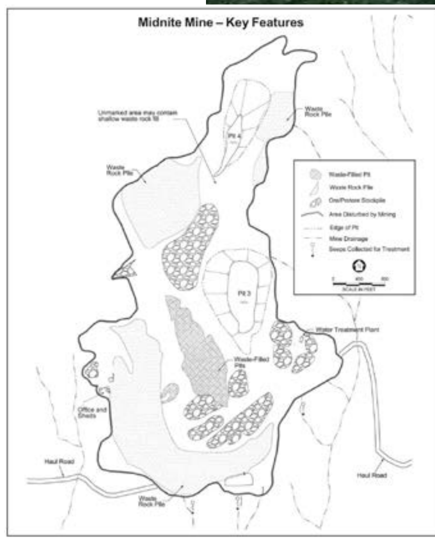
International Atomic Energy Agency (IAEA) has determined that uranium mine waste rock and uranium mill tailings both require similar management systems as both are radioactive waste containing sources of risk including long-lived radioisotopes and heavy metals.

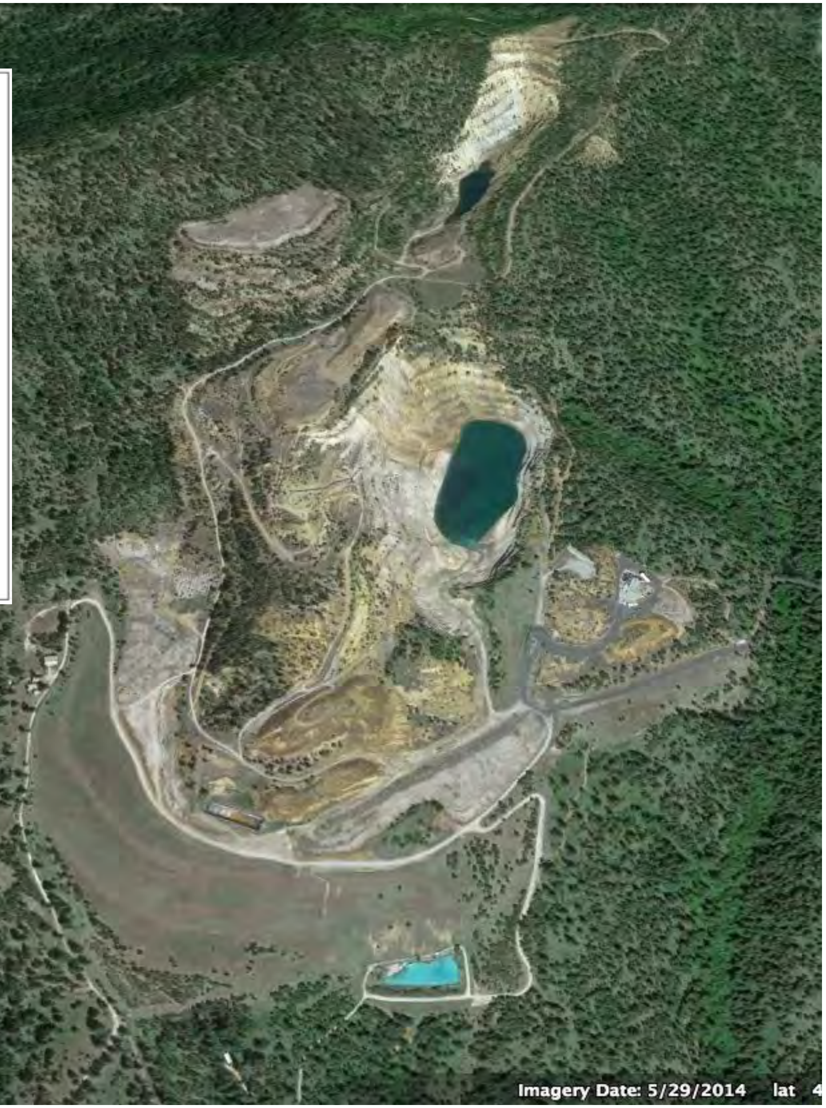
"[S] since mine and mill tailings will continue to present a potential hazard to human health after closure, additional analyses and measures may be needed to provide for the protection of future generations. Such measures should not be left until closure but should be considered and implemented throughout 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."

Source: "MANAGEMENT OF RADIOACTIVE WASTE FROM THE MINING AND MILLING OF ORES--SAFETY GUIDE," INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2002, http://www-pub.iaea.org/MTCD/publications/PDF/Pub1134_scr.pdf

Midnite Mine Remedial Plan







Remedial Design – 2012-2015

Early Works and Phase 1– 2015 – 2018
- Access Road
- Mobilization
- Construction Support Zone Site Preparation
- Alluvial Groundwater Collection System
- West Access Road cleanup
- Pit 4 Dewatering and Pit Preparation
- Pit 4 Backfilling
- Water Treatment Plant (WTP) Construction
- South Pond Construction
- Cover Borrow Area Preparation
- Pit 4 Cover System and Revegetation

Phase 2 - 2018 - 2021
- Pit 3 Dewatering and Preparation
- Pit 3 and BPA Phase II Backfill
- Eastern Drainage, Western Drainage Sediment Removal
- East Access Road cleanup
- Old WTP Demolition
- West Pond Construction
- Area 5 Grading and Capping

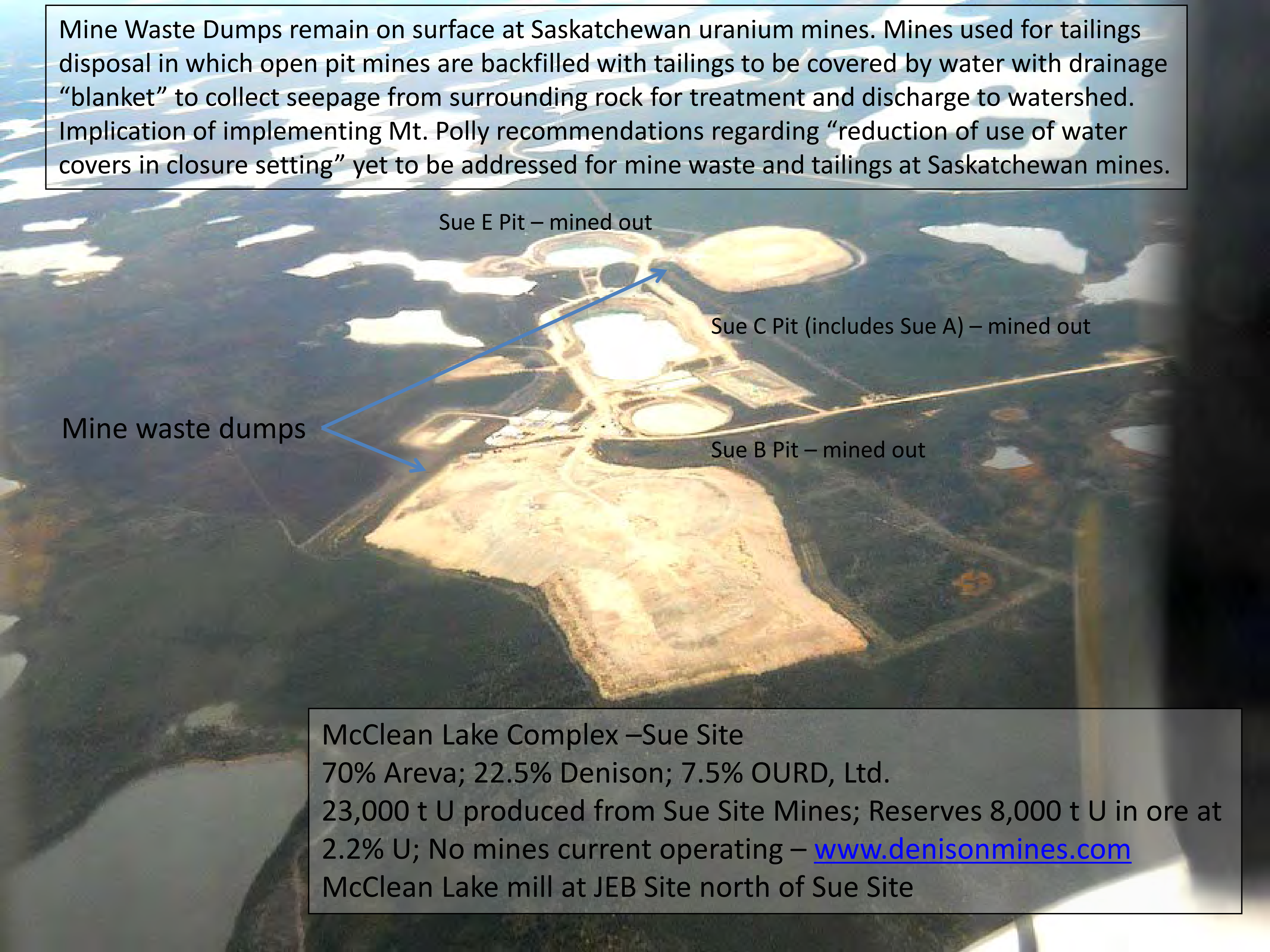
Phase 3 – 2022 - 2024
- South Dump Pond Removal
- Central Drainage Mine Waste Rock and PCP Removal
- Central Drainage Sediment Removal
- Area 5 Grading
- Site/Decontamination Area Cleanup
- Pit 3 and BPA Cover System System

Post Remediation – 2025 onward
- Ongoing Water Treatment
- Site Monitoring and Maintenance
- West Pond Decommissioning

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.

Midnite Mine information available at: http://yosemite.epa.gov/R10/CLEANUP.NSF/sites/midnite

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.



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
McClean Lake mill at JEB Site north of Sue Site

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

Sample	Parameter		
	U (µg/L)	As (µg/L)	pH
Spring	163	5.7	7.4
Seep	135	9.6	3.8
MCL	30	10	

“Claim 28” Mine Waste Analyses

	Elemental Content, ug g^{-1}							
	Si	S	Al	Fe	Mg	U	V	Ca
Undisturbed Soil	241,950	1,339	52,129	26,739	3,068	BDL*	BDL*	16,441
Mine waste1	235,563	223	69,533	15,259	181	2,248	15,814	855
Mine waste2	243,703	1,834	59,730	3,511	405	6,614	4,328	3,293

Source: Uranium in Soil, Mine Waste and Spring Water near Abandoned Uranium Mines Tachee/Blue Gap and Black Mesa Chapters, Navajo Nation, AZ http://www.sric.org/uranium/docs/METALS_Monograph1_Final_040814a.pdf

Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings (40 CFR 192) - http://www.epa.gov/radiation/laws/192.html

The first revision to this standard since 1995 would establish ground water restoration goals and monitoring requirements at ISR facilities

Revision of EPA Rule 40CFR192 Is a current policy issue.

Public hearings are being held in April 2015.

Comments on the Proposed Rules are being received until May 27, 2015

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

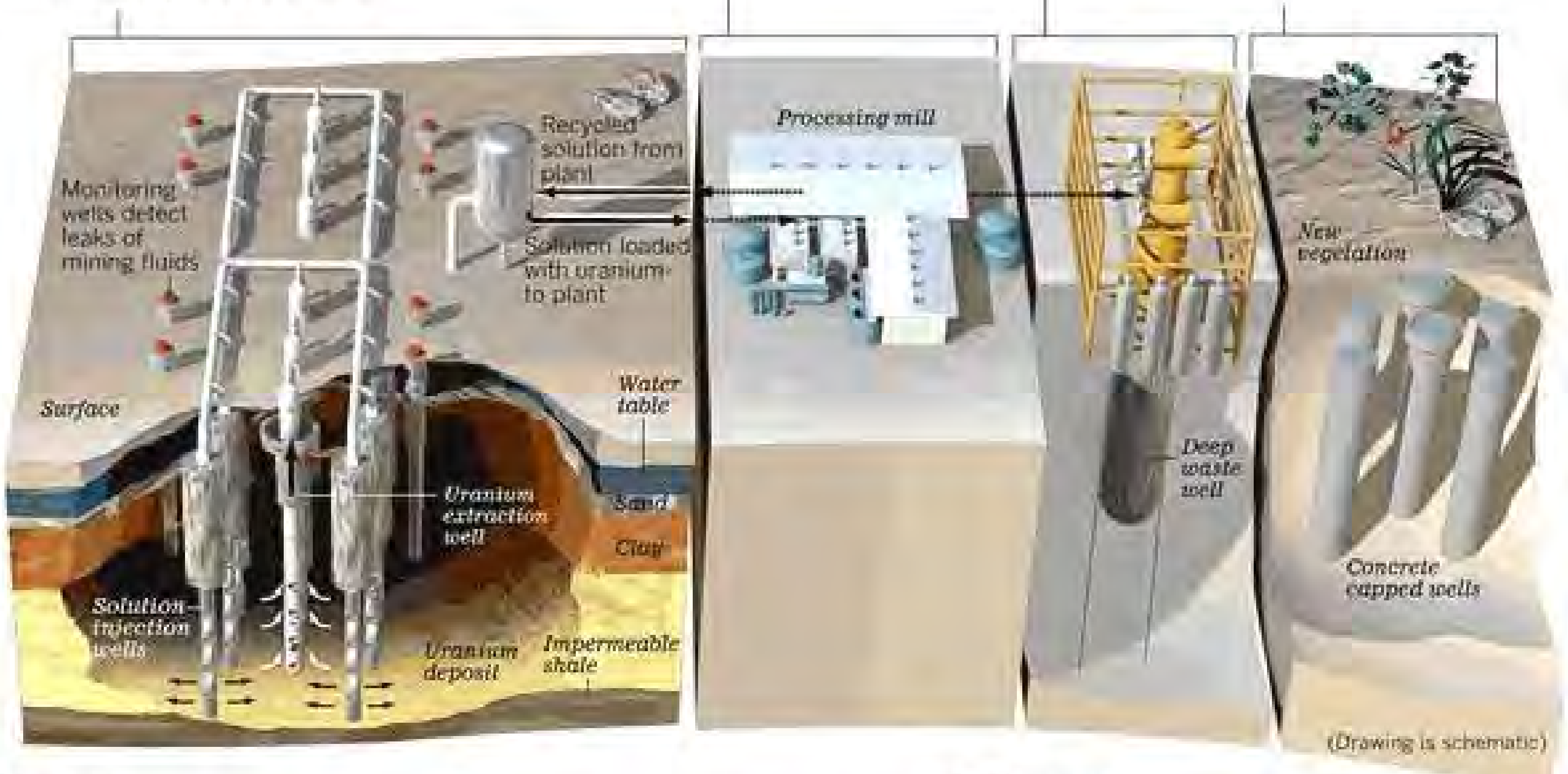
Solution mining

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.

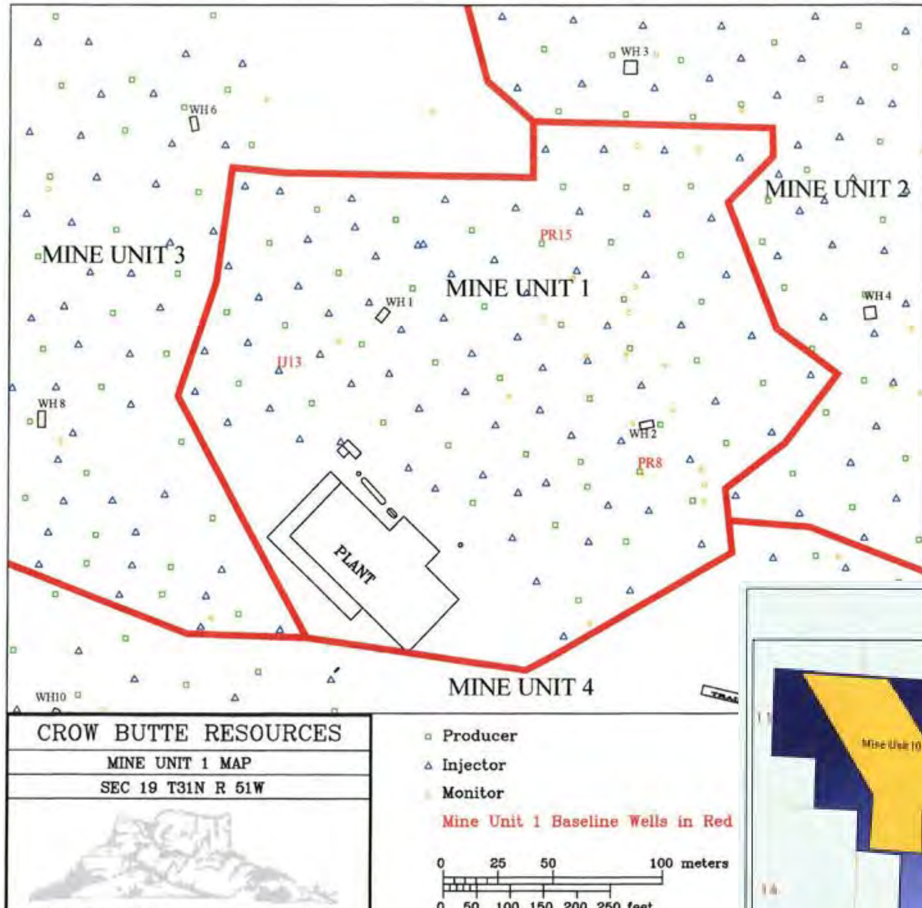
Restoration
Water is purified and reinjected into the well field. Wells are later filled with concrete and capped below the surface. Surface soil is decontaminated if necessary.

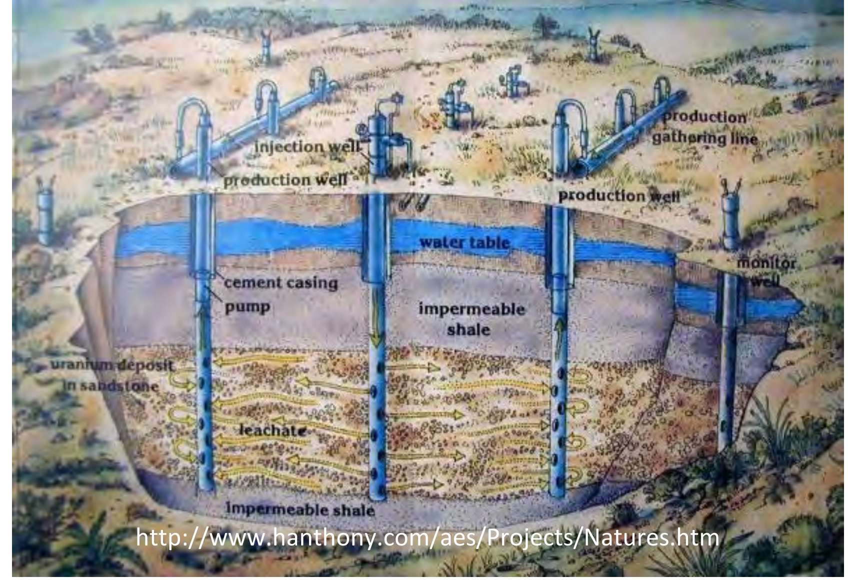


Advantages
- Minimal surface disturbance.
- No mine to rehabilitate.
- Does not create excess rock piles or tailings from processing.
- Can be used for small deposits that are not economical for conventional mining.
- Uranium can be processed on site.
- Less time is needed for establishing and maintaining 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: Uranium Producers of America, Environmental Protection Agency, National Energy Institute, Bureau of Land Management, Utah Geological Survey, Uranium Resources, Inc.
Graphics reporting by TOM REINKEN*; Graphic by* LORENA IÑIGUEZ *Los Angeles Times*


WH 3
WH 6
MINE UNIT 2
PR15
MINE UNIT 3
MINE UNIT 1
WH 1
WH 4
U13
WH 8
WH 2
PR8
PLANT
MINE UNIT 4
WH10
CROW BUTTE RESOURCES
MINE UNIT 1 MAP
SEC 19 T31N R 51W
Producer
Injector
Monitor
Mine Unit 1 Baseline Wells in Red
0 25 50 100 meters
0 50 100 150 200 250 feet


injection well
production well
production gathering line
production well
water table
monitor well
cement casing
pump
impermeable shale
uranium deposit in sandstone
leachate
impermeable shale
http://www.hanthony.com/aes/Projects/Natures.htm


Kingsville Dome ISL Mine, Texas
http://www.hanthony.com/aes/Projects/KVD.htm

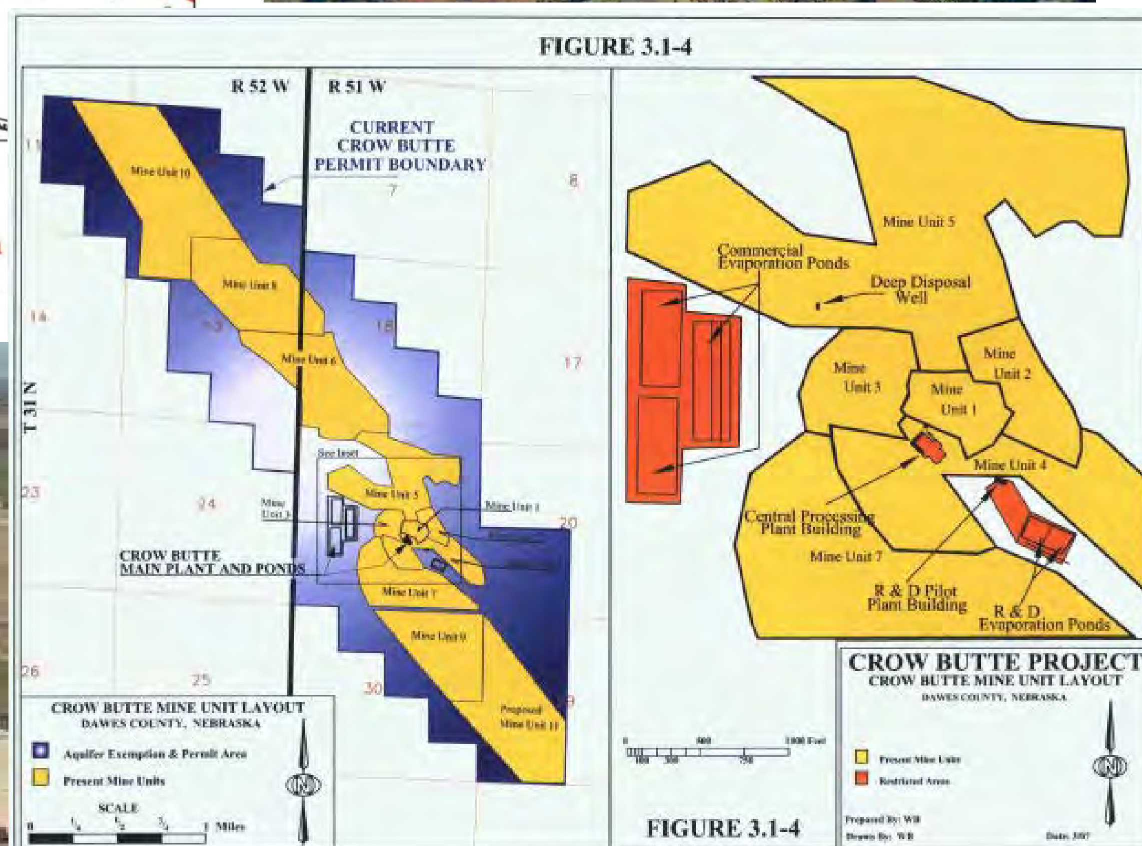


FIGURE 3.1-4
R 52 W
R 51 W
CURRENT CROW BUTTE PERMIT BOUNDARY
Mine Unit 10
Mine Unit 8
Mine Unit 6
T 31 N
See Inset
Mine Unit 5
Mine Unit 3
Mine Unit 1
CROW BUTTE MAIN PLANT AND PONDS
Mine Unit 7
Mine Unit 9
Proposed Mine Unit 11
CROW BUTTE MINE UNIT LAYOUT
DAWES COUNTY, NEBRASKA
Aquifer Exemption & Permit Area
Present Mine Units
SCALE
Miles
Mine Unit 5
Commercial Evaporation Ponds
Deep Disposal Well
Mine Unit 3
Mine Unit 1
Mine Unit 2
Mine Unit 4
Central Processing Plant Building
Mine Unit 7
R & D Pilot Plant Building
R & D Evaporation Ponds
CROW BUTTE PROJECT
CROW BUTTE MINE UNIT LAYOUT
DAWES COUNTY, NEBRASKA
Present Mine Units
Restricted Areas
FIGURE 3.1-4

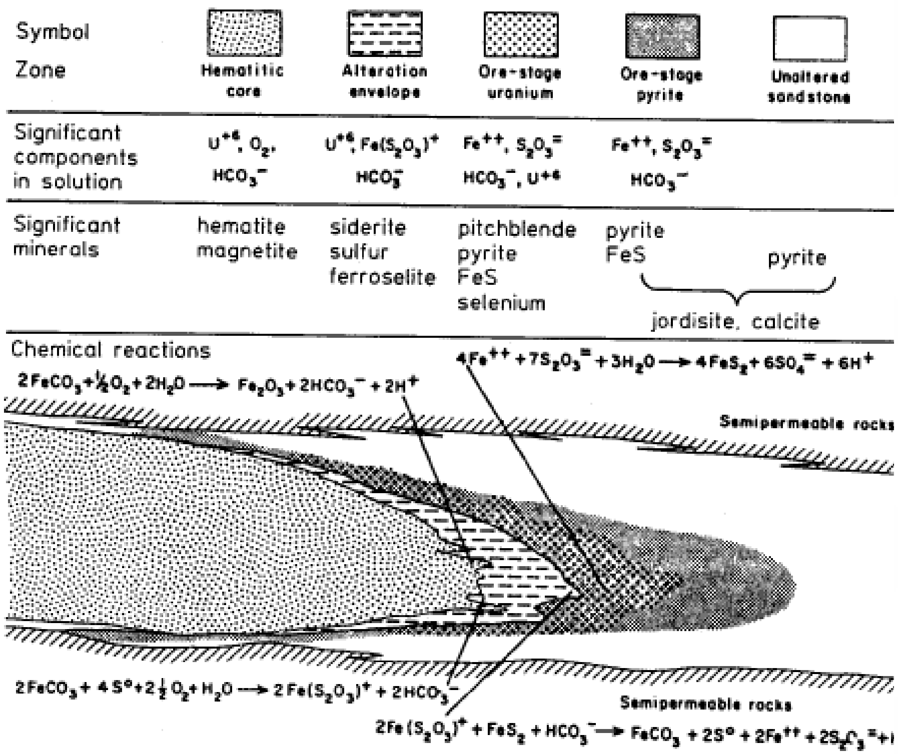


Figure 3. Schematic of idealized Wyoming Basin uranium roll front deposit showing alteration zones, related mineral components, solution components, and important aqueous chemical reactions for Fe, S, O, and CO_2 (after Granger and Warren, 1974).

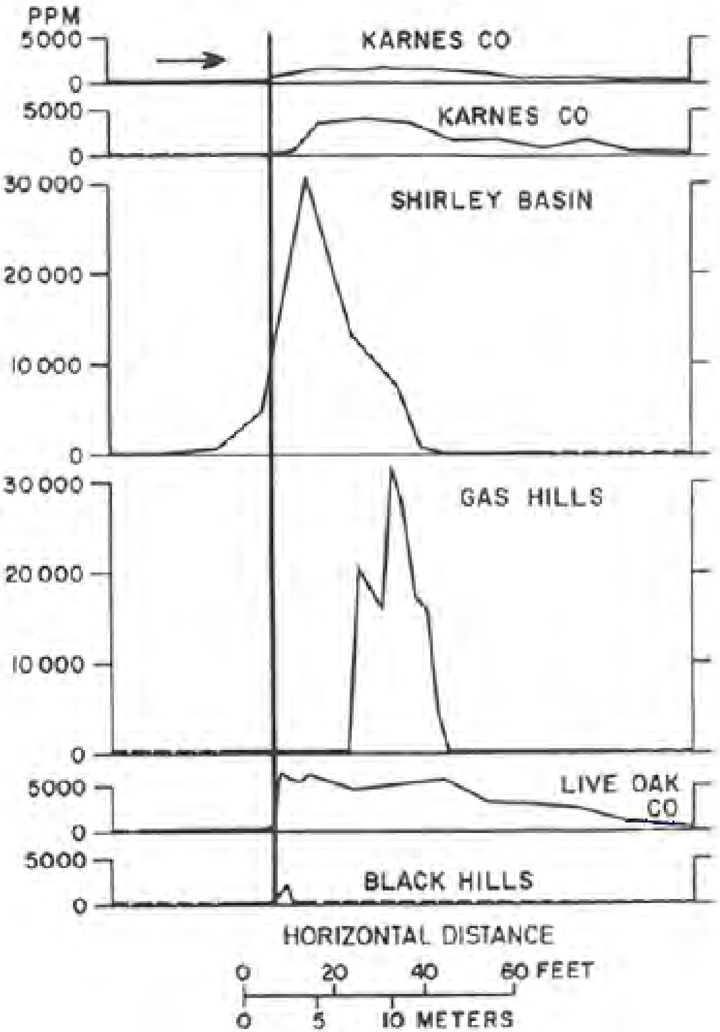


Figure 5. Concentration and distribution of uranium in various roll front deposits (after Harshman, 1974).

Cameco-Owned Crow Butte In Situ Uranium Mine, Nebraska

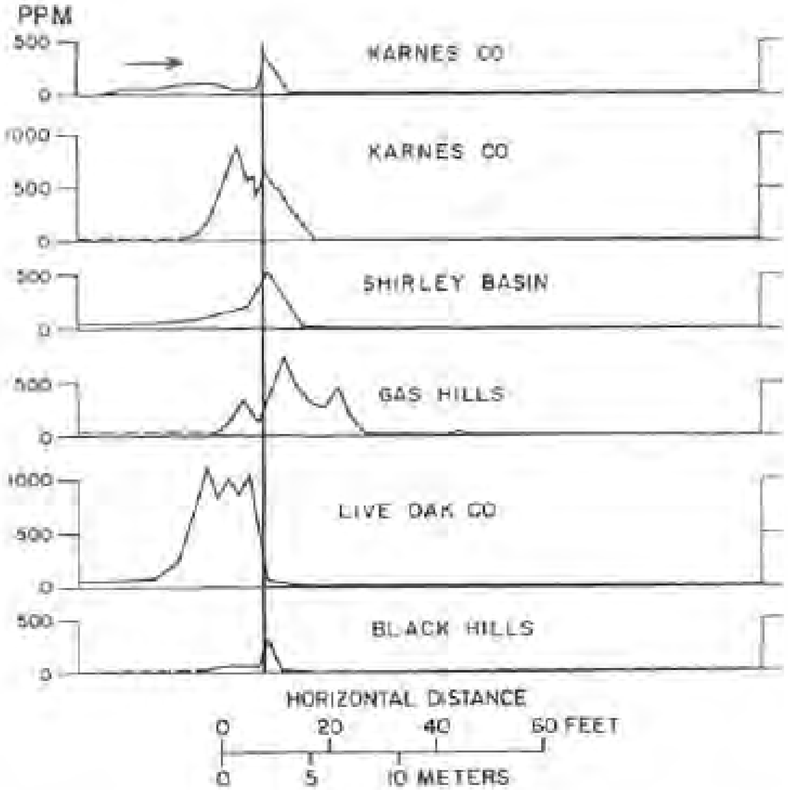


Figure 6. Concentration and distribution of selenium in various uranium roll front deposits (after Harshman, 1974).

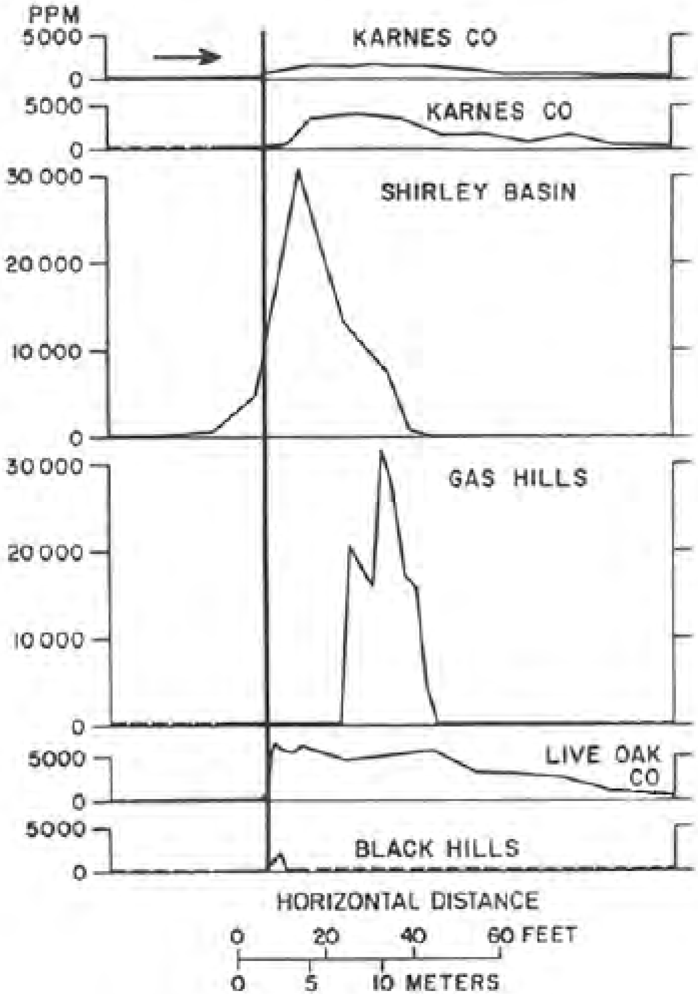


Figure 8. Concentration and distribution of arsenic in various uranium roll front deposits (after Harshman, 1974).

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,
http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6870/

…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, SO_4, O_2

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