Overview of Uranium Recovery Facilities

Module Objectives

- Describe the various operations at a conventional uranium mill.
- Describe the various operations at an in-situ uranium recovery facility.

Conventional Uranium Mills

Cotter Uranium Mill (and golf course)

Unloading Uranium Ore

Uranium mills are in close proximity to uranium mines.

Ore Pad Construction

- Designed to mitigate leaching of ore.
- Ore can be on pads for several years
- What type of dust suppression is being employed?

Courtesy of Phil Egidi

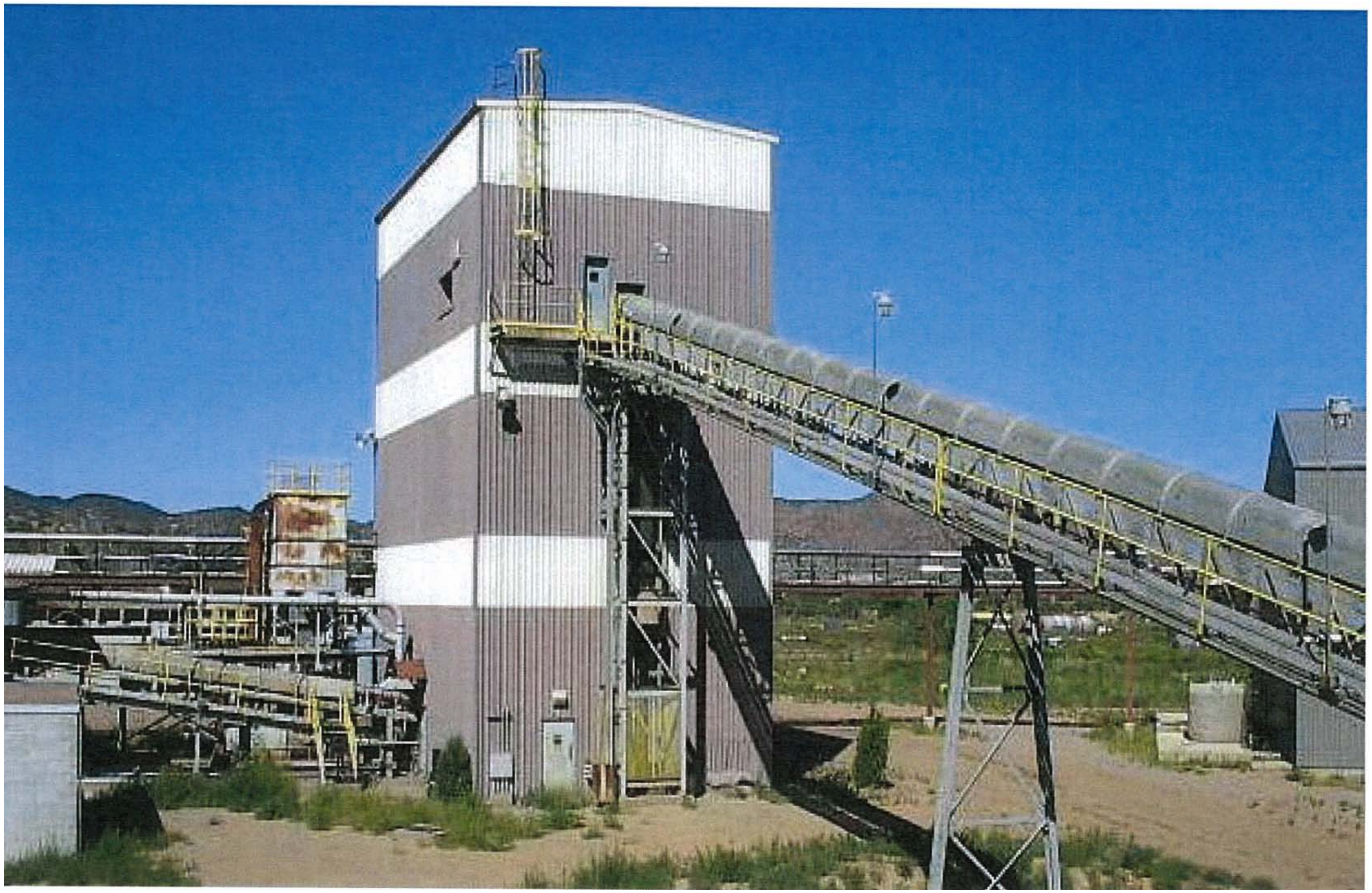
Overturned Ore Truck

Courtesy of Phil Egidi

Feed Material

- The process stream at a conventional mill is adjusted to accommodate the type of feed material.
- To keep the mill profitable, uranium might not be the only material that is extracted from the ore. For example, the extracted vanadium might be more valuable than the uranium.
- Some feed materials might contain enough thorium to warrant bioassay.

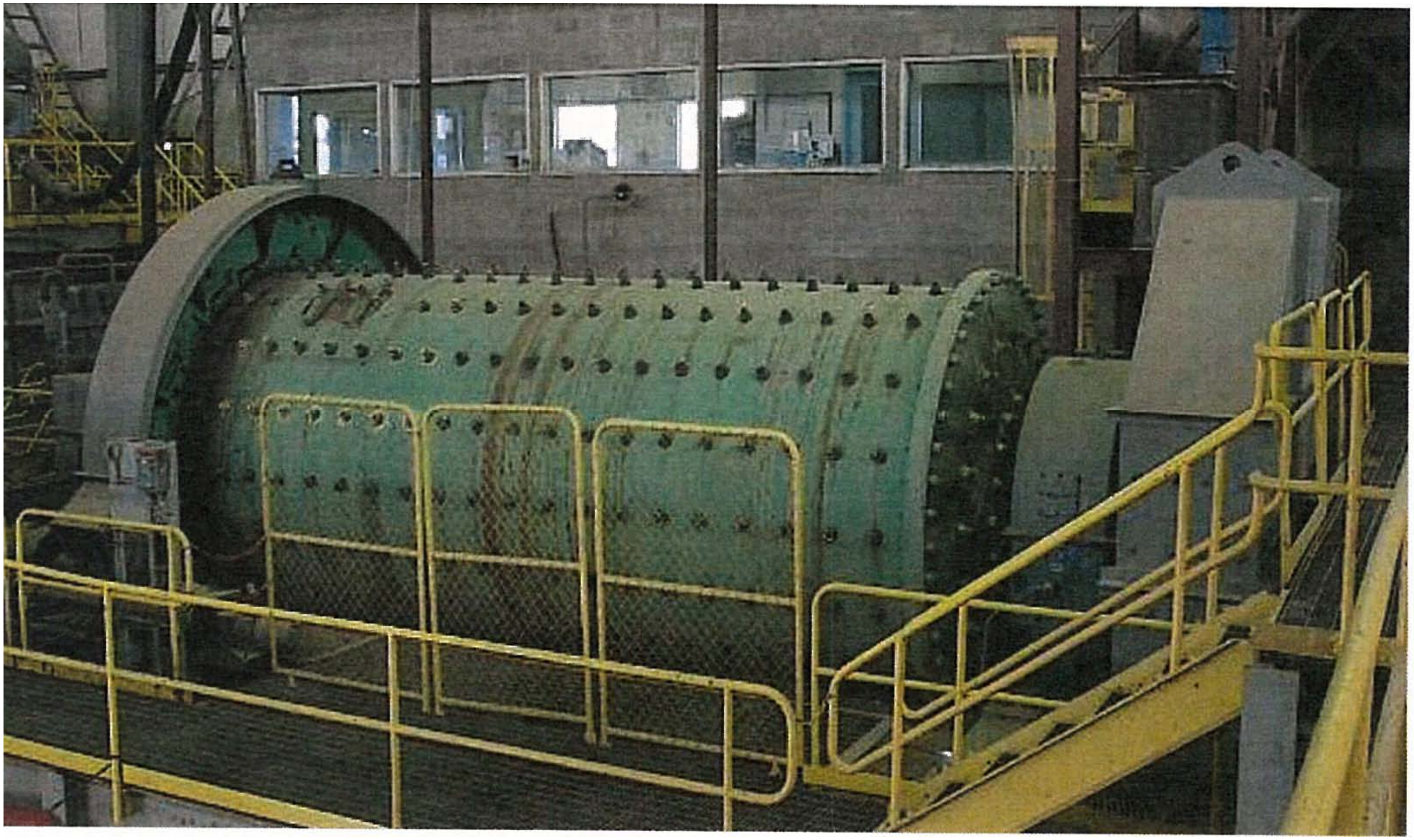
Ore on Conveyor to Crusher



Fine Ore Bins

- High indoor radon potential.
- External exposures a potential issue.
- Next, the fine (crushed) ore goes to ball mill.

Ball Mill



Ball Mill

- Loud, noisy.
- One of many industrial hazards at conventional mill.
- Milled ore goes to leaching tanks.

SAG Mill

- Semi-autogenous grinding (SAG) mills use a wet process that results in fewer airborne emissions than the ball (or rod) mills.

Bag Houses

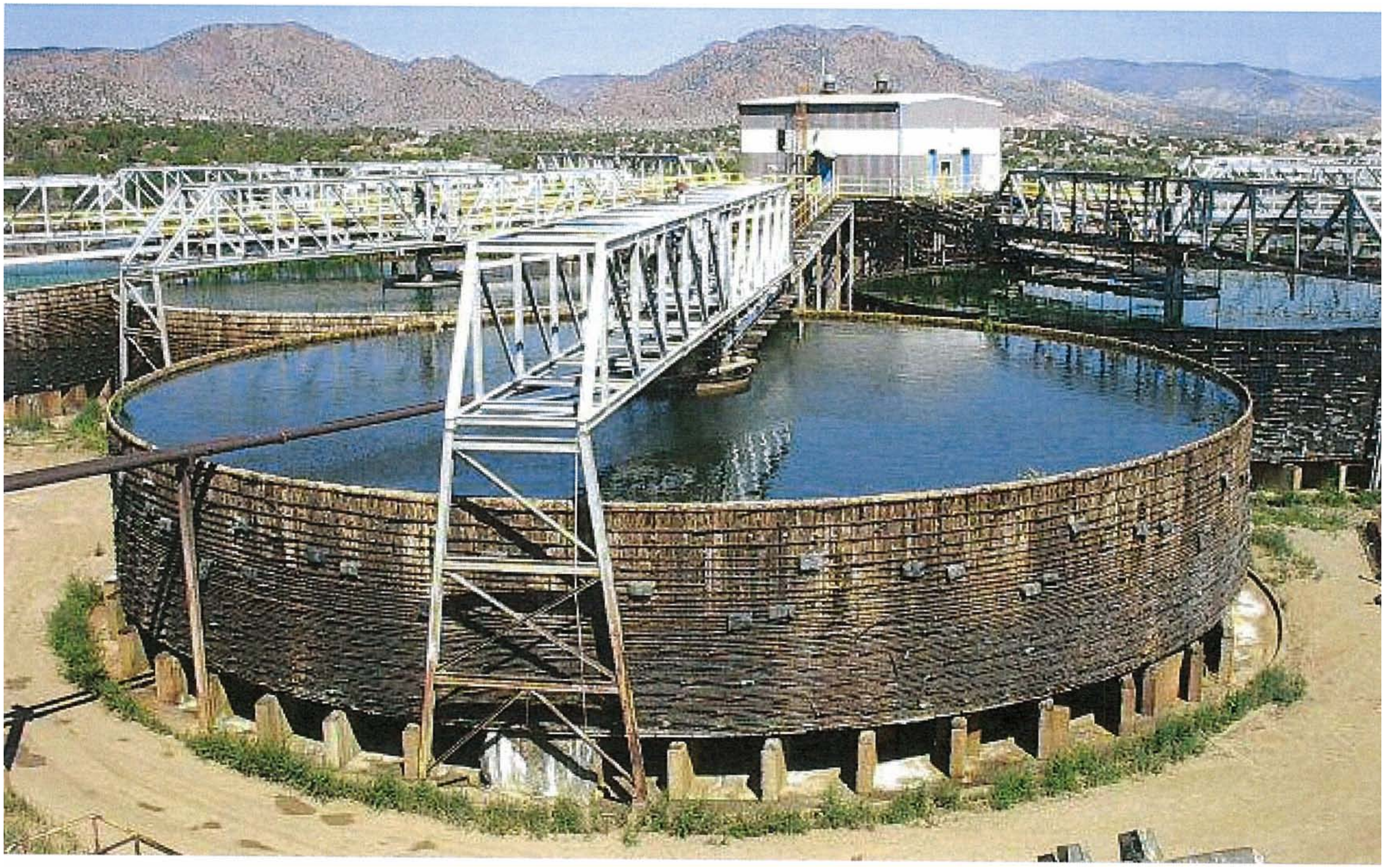
Courtesy of Cotter Corp.

Leach Tanks

Courtesy of
Cotter Corp.

- Acid leach gets uranium into solution.
- Next, the slurry of uranium-rich solution and particulates is transferred to the CCD tanks for separation.

Counter Current Decanter Tanks (Thickeners)



Courtesy of Cotter Corp.

Counter Current Decanter Tanks (Thickeners)

Courtesy of Phil Egidi

Several (e.g., seven) tanks are grouped into a “farm” or circuit.

These CCD tanks can leak.

Might be made of wood, steel, fiberglass.

Counter Current Decanter Tanks (Thickeners)

- The goal of the CCD thickeners is to separate the acidic liquid containing the uranium from the solids (the leached ore).

- The solids and solutions move from one tank to another, but in opposite directions.

- The result is that the solids accumulate in the tank at one end of the circuit while the liquids end up in the tank at the far end of the circuit.

- The solids (i.e., the leached ore) are sent to a tailings pond.

Solvent Extraction


Courtesy of Cotter Corp.

- After filtration, the uranium is preferentially extracted into an organic solvent (e.g., kerosene).

- Some of the metals remaining in the acidic aqueous solution (e.g., vanadium) might be extracted separately.

- Next, the uranium is ‘stripped” from the organic solvent into an acidic aqueous brine.

- The chemical fumes can make breathing difficult.

Uranium Precipitation

Courtesy of Cotter Corp.

- The dissolved uranium is precipitated (into suspension) by the addition of heat, air and ammonia. It is then dried and drummed.

Left: precipitation tank.

Below: anhydrous ammonia tank.

Courtesy of Phil Egidi

Tailings Pond/Impoundment

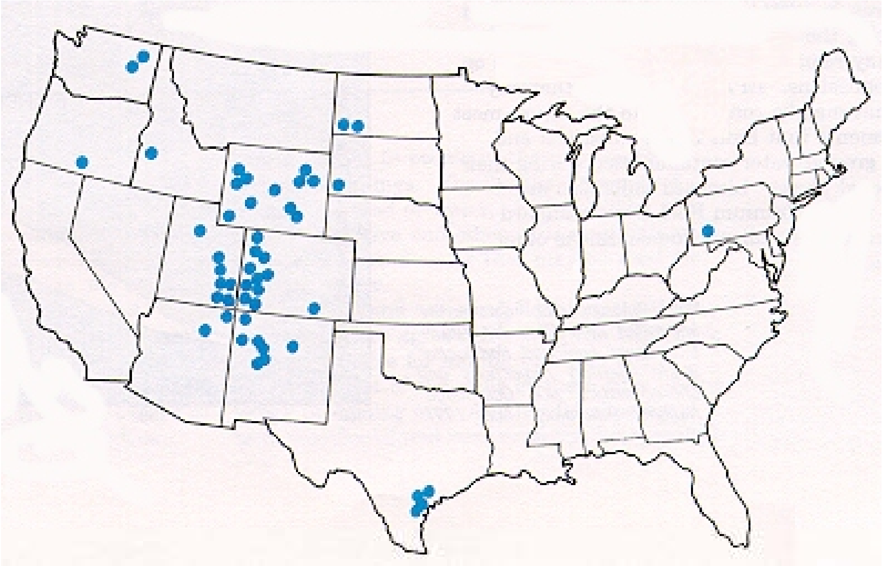
- Tailings, primarily leached ore, accumulate in impoundments (aka ponds).
- The water minimizes radon emanation and production of airborne particulates.
- As the impoundment fills, water is transferred to evaporation ponds.

Tailings Pond/Impoundment

Courtesy of Cotter Corp.

- Dust suppression will be employed around the periphery of the impoundment.
- Dried areas are known as the “beach.”

Mill Tailings



Locations of mill tailings piles in the U.S.

http://www.epa.gov/rpdweb00/docs/radwaste/402-k-94-001-umt.html

Principal long-lived components of mill tailings: Th-230 and Ra-226

Main exposure pathways:

1. **radon emanation**
2. **gamma exposure (exposure rates are essentially the same as with the ore)**
3. **contamination of ground water**

Tailings Pond/Impoundment

Courtesy of Phil Egidi

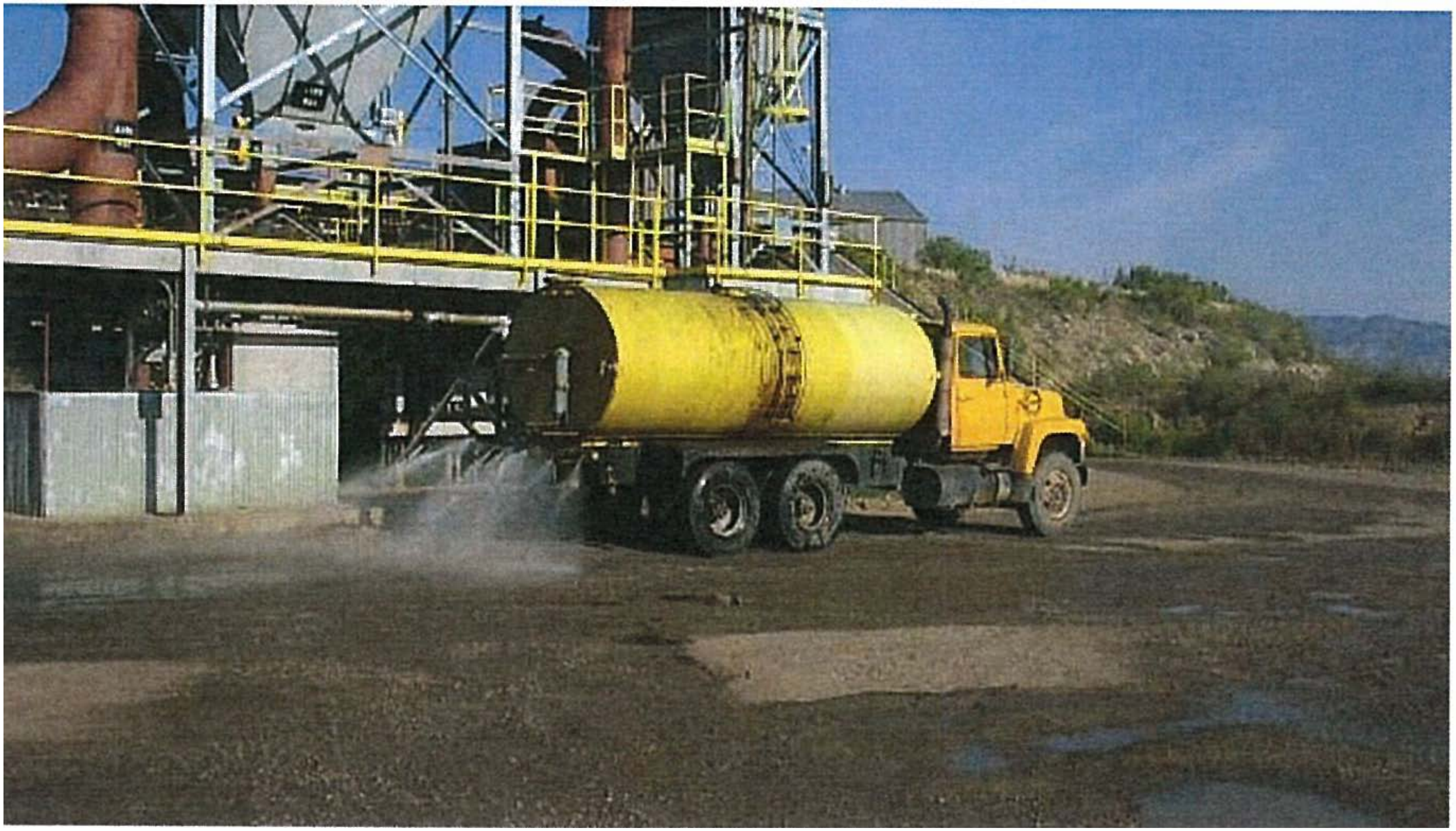
- Integrity of the engineered pond lining is important.
- Liner must be inspected and maintained.

Evaporation Pond

Courtesy of Cotter Corp.

- On occasion, airborne firefighters have been known to collect water from on-site ponds without consultation.
- A mill might have a designated pond for fire fighting purposes.

Dust Control



In-situ Leach Uranium Recovery Operation

Sandstone Deposits

- Sandstone deposits of uranium, such as those in Wyoming, Colorado and Texas represent approximately 18% of the worlds uranium resources.
- These sandstone deposits are typically low to medium grade (< 1% uranium)
- The uranium, original mobilized in groundwater, precipitated when it encountered a reducing environment within the sandstone. The reducing agents responsible might be some combination of carbonaceous material, sulphides and hydrocarbons.

Oxidation of the Uranium in the Ore Body

- The uranium in the ore body is oxidized and mobilized by pumping in a lixiviant solution.
- O_2 or H_2O_2 is added to the lixiviant so as to oxidize the uranium to the hexavalent state which is more soluble than tetravalent UO_2.

$$2(UO_2) + O_2 \rightarrow 2(UO_3)$$

uranium dioxide → uranium trioxide

Dissolution and Mobilization of the Uranium in the Ore Body

- A complexing agent in the lixiviant (e.g., a bicarbonate) mobilizes the uranium.

$$UO_3 + 2(MHCO_3) \rightarrow M_2UO_2(CO_3)_2 + H_2O \text{ or}$$

$$UO_3 + D(HCO_3)_2 \rightarrow DUO_2(CO_3)_2 + H_2O$$

M is a monovalent cation and D is a divalent cation.

uranium trioxide → uranium carbonate

Dissolution and Mobilization of the Other Materials in the Ore Body

- The lixiviant not only mobilizes the uranium, it also mobilized other elements commonly associated with uranium deposits, e.g., radium
  arsenic
  selenium
  iron

Ultimately, these materials must be removed from the groundwater so that the latter is restored to its original condition.

Radionuclides in the Lixiviant

- The major radionuclides brought to the surface in the lixiviant are:
    - U-234
    - U-235
    - U-238
    - Rn-222 (plus short-lived decay products ingrowth)
    - Ra-226 (relatively low concentrations)

The Well Field

- There are four types of wells at an ISL facility:

    injection wells

    production wells

    groundwater monitoring wells

    deep disposal wells

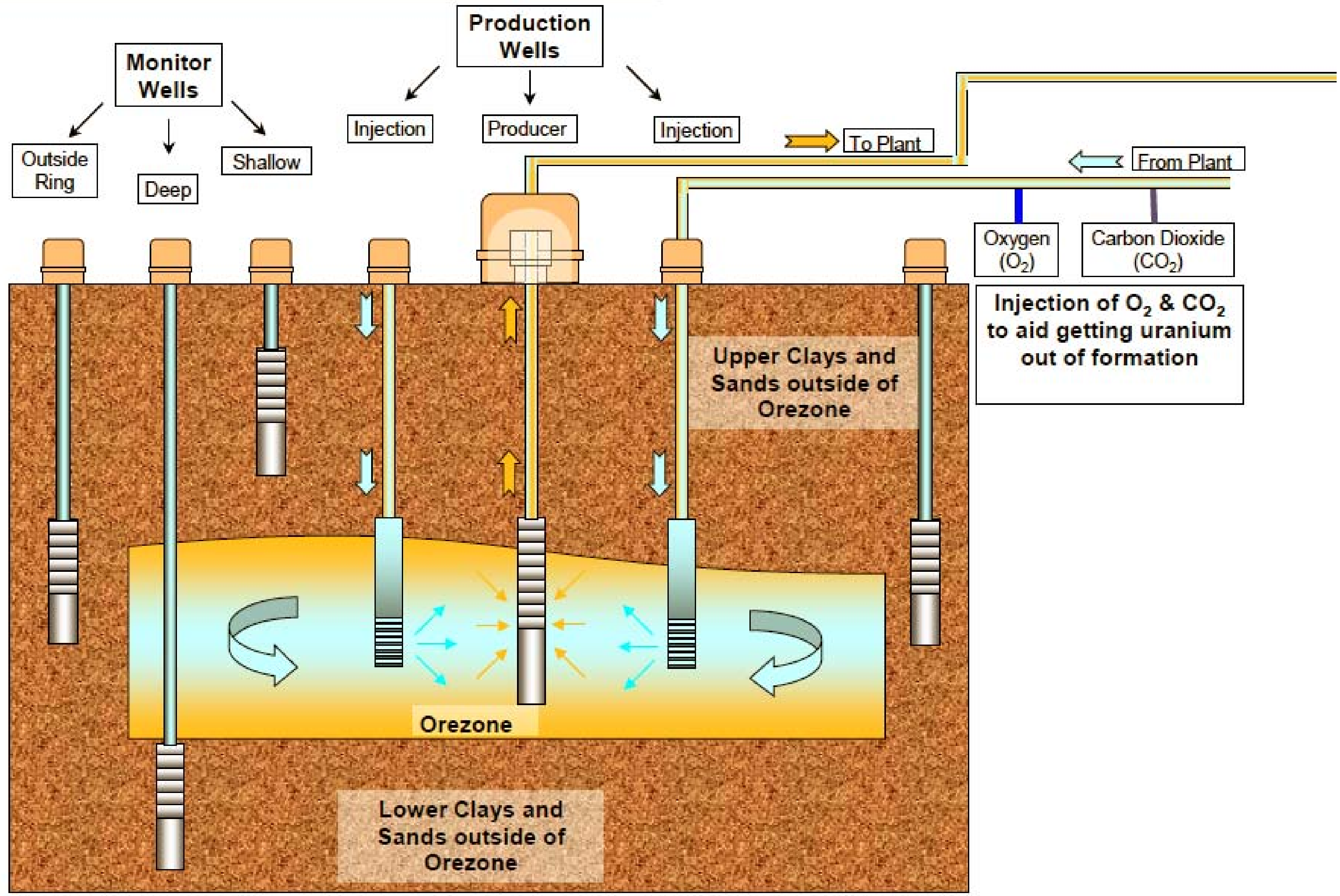
The Well Field

Injection Wells:	**Pump the lixiviant solution into the ore body.**
Production Wells:	**Are surrounded by the injection wells. Remove the groundwater and lixiviant in which the uranium (and other materials) is mobilized.**

The Well Field

Monitoring Wells:	Sample groundwater around, above and below the ore body. Ensures that mobilized uranium and other materials do not escape the well field
Disposal Wells:	Very deep (e.g., 10,000 feet or more). Certain waste solutions (e.g., purge) are injected into these wells. These very deep aquifers would not be suitable as a source of drinking water.

PRODUCTION: Getting Uranium Out of the Ground



Monitor Wells

Outside Ring

Deep

Shallow

Production Wells

Injection

Producer

Injection

To Plant

From Plant

Oxygen (O_2)

Carbon Dioxide (CO_2)

Injection of O_2 & CO_2 to aid getting uranium out of formation

Upper Clays and Sands outside of Orezone

Orezone

Lower Clays and Sands outside of Orezone

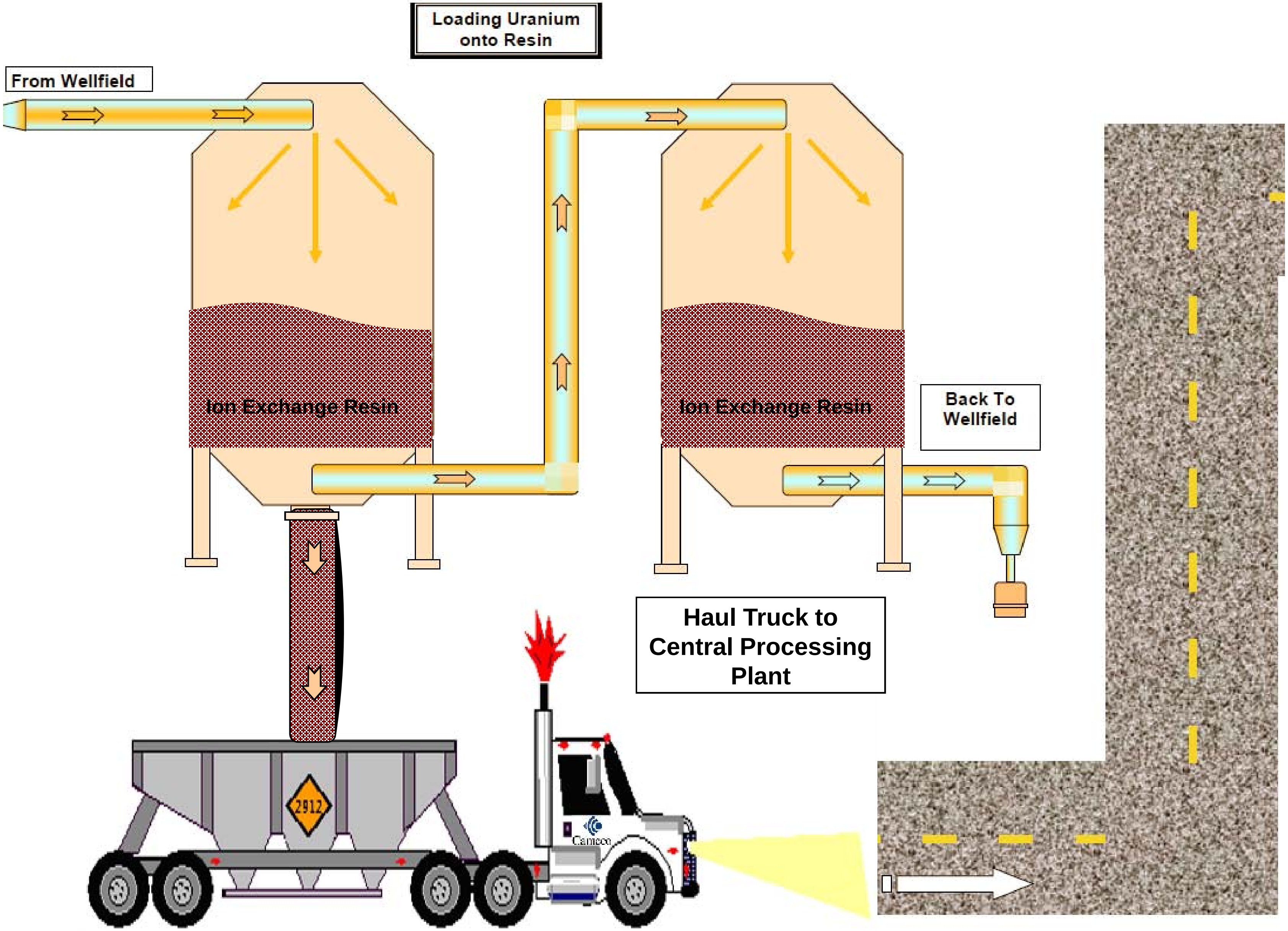
The Well Field

- More solution is extracted from the production wells than goes into the injection wells. This is accomplished by purging ca. 1% of the extracted solution.
- This is done to ensure that the net movement of the groundwater is towards the central production wells. Otherwise, the groundwater beyond the production well field could become contaminated.
- The flow to and from the wells is controlled at a "header house."


40/HP
FLA
53.5

Ion Exchange

- The solution extracted from the production wells is run through an ion exchange resin that removes the uranium.
- This might be done at a central production facility or a “satellite” facility located near a remote production well field.
- In the latter case, the resin with the extracted uranium will be trucked from the satellite facility to the central processing facility.
- The barren solution leaving the ion exchange tanks (minus the purge) is returned to the well field for injection.



Loading Uranium onto Resin

From Wellfield

Ion Exchange Resin

Ion Exchange Resin

Back To Wellfield

Haul Truck to Central Processing Plant

Uranium Elution from Resin

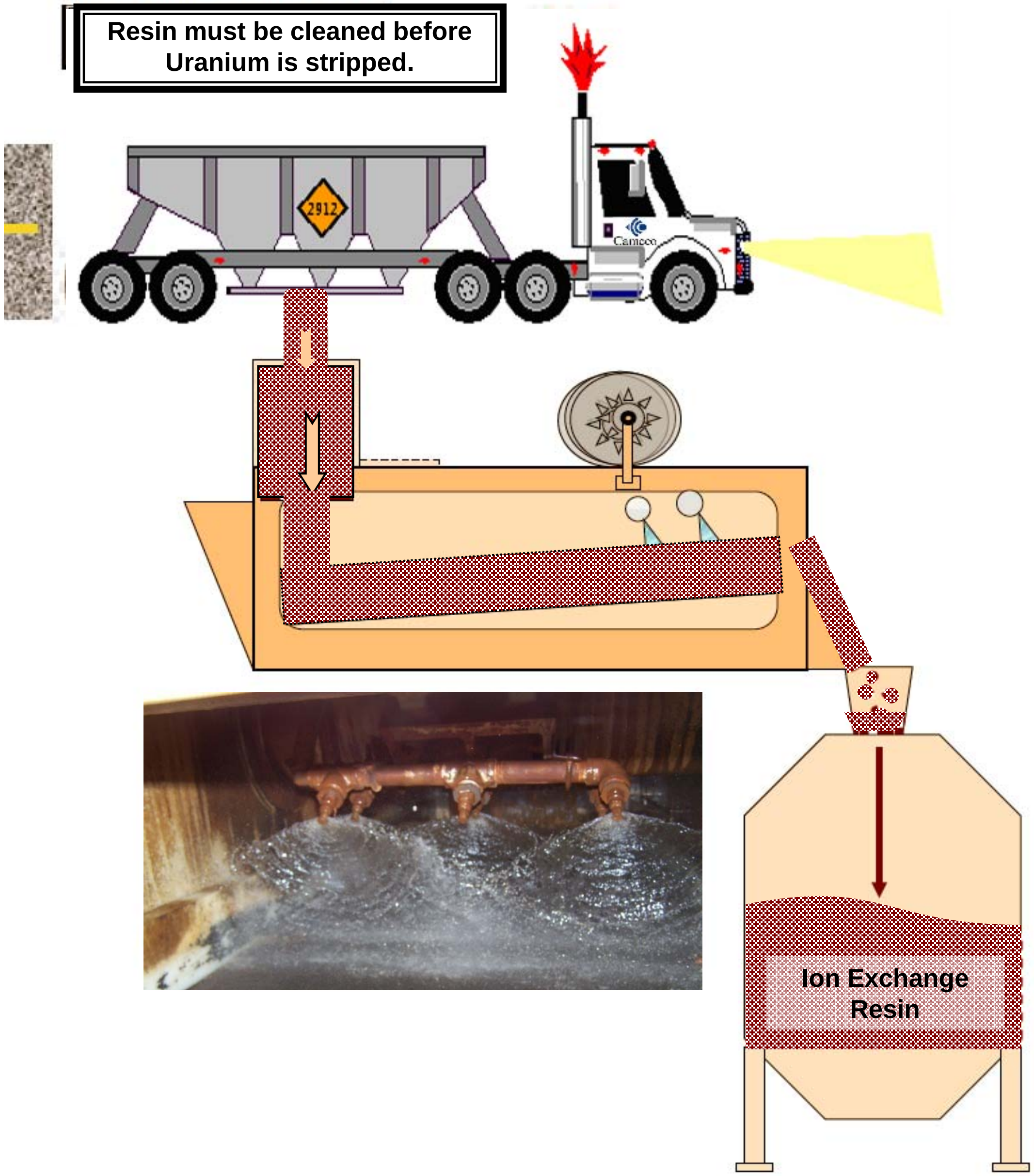
- When sufficient uranium has been adsorbed on the resin, the ion exchange system is taken off line.
- The resin is cleaned prior to the elution of the uranium.
- This is done at the “shaker table.”
- Some radium and radon (plus decay products) will be associated with, but not bound to, the resin. Along with the uranium, these are the primary radionuclides found in the solution extracted from the production wells.

Uranium Elution from Resin

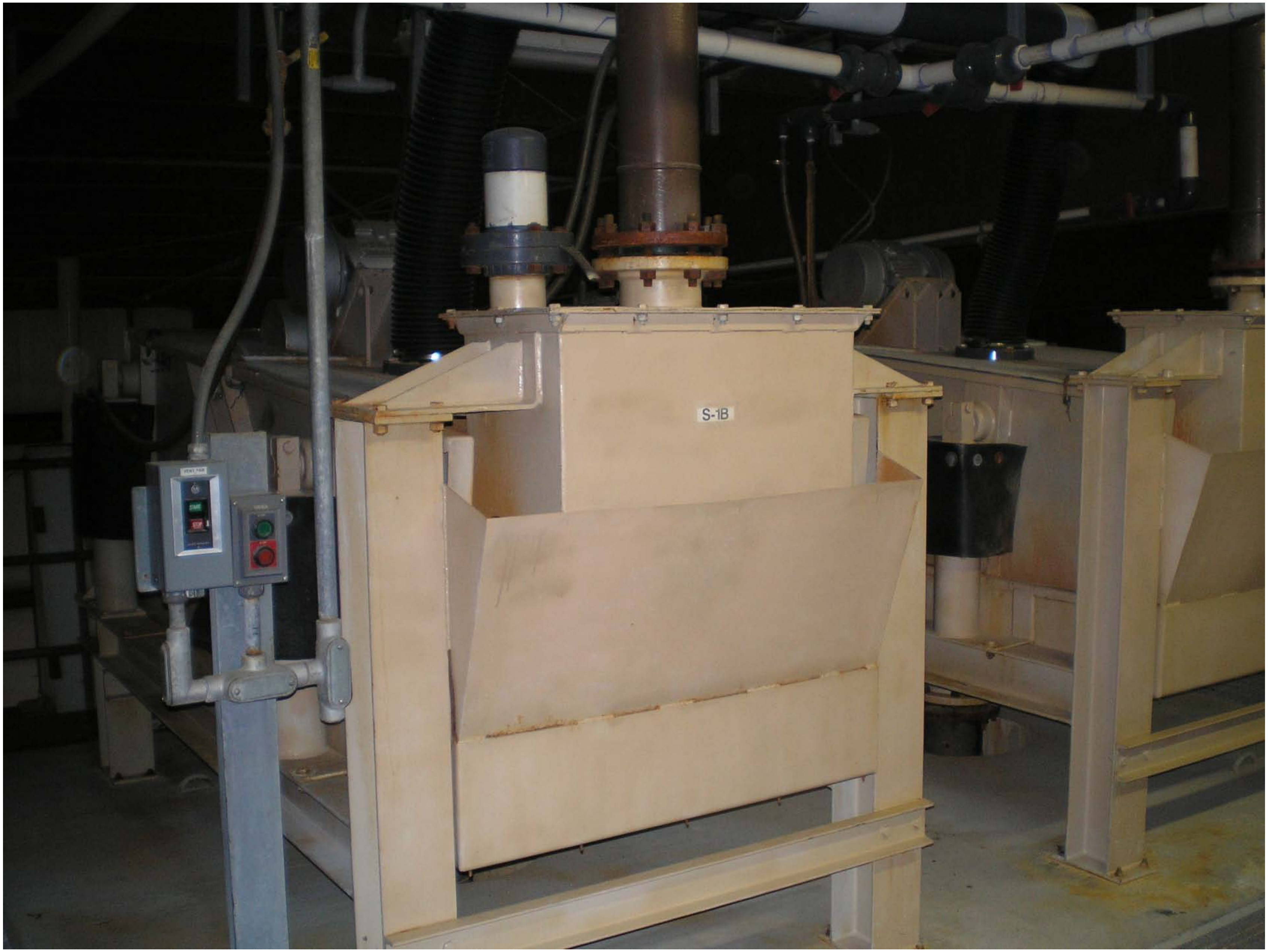
- Radon will be released during ion exchange, resin washing, and elution steps.

- Some systems will release radon to general room air. Other systems will be enclosed and control the radon via local exhaust systems.

Resin must be cleaned before Uranium is stripped.




RADIOACTIVE
7
2912
HAND OFF AUTO

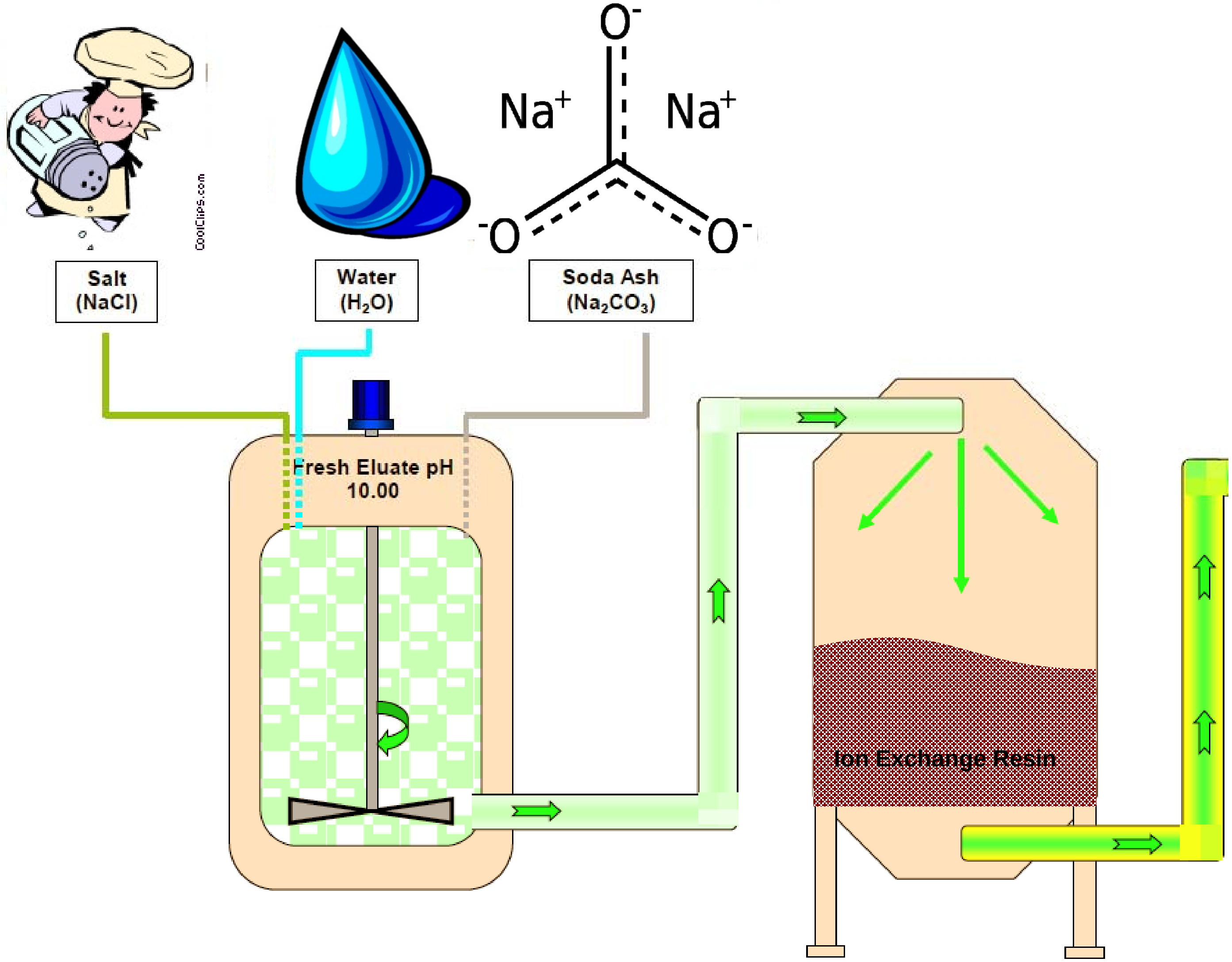

S-1B

Uranium Elution from Resin

- A brine solution (containing Cl^- ions) is run through the resin to strip off the uranium.
- The Cl^- ions replace the uranium at the binding sites on the resin surface thereby recharging the resin.
- Carbonate or bicarbonate (e.g., soda ash) is added to prevent the uranium from precipitating in the elution tank.
- The uranium containing eluant is referred to as “rich” or “pregnant.”
- One liter of the pregnant eluant might contain 8 – 20 grams of uranium.

A Recipe of Salt, Water, and Soda Ash to Make "Fresh Eluate"

"Elution": Process where uranium is stripped from the resin.



Uranium Precipitation

- Hydrochloric or sulfuric acid is added to the pregnant eluant to break up the uranium carbonate complex.

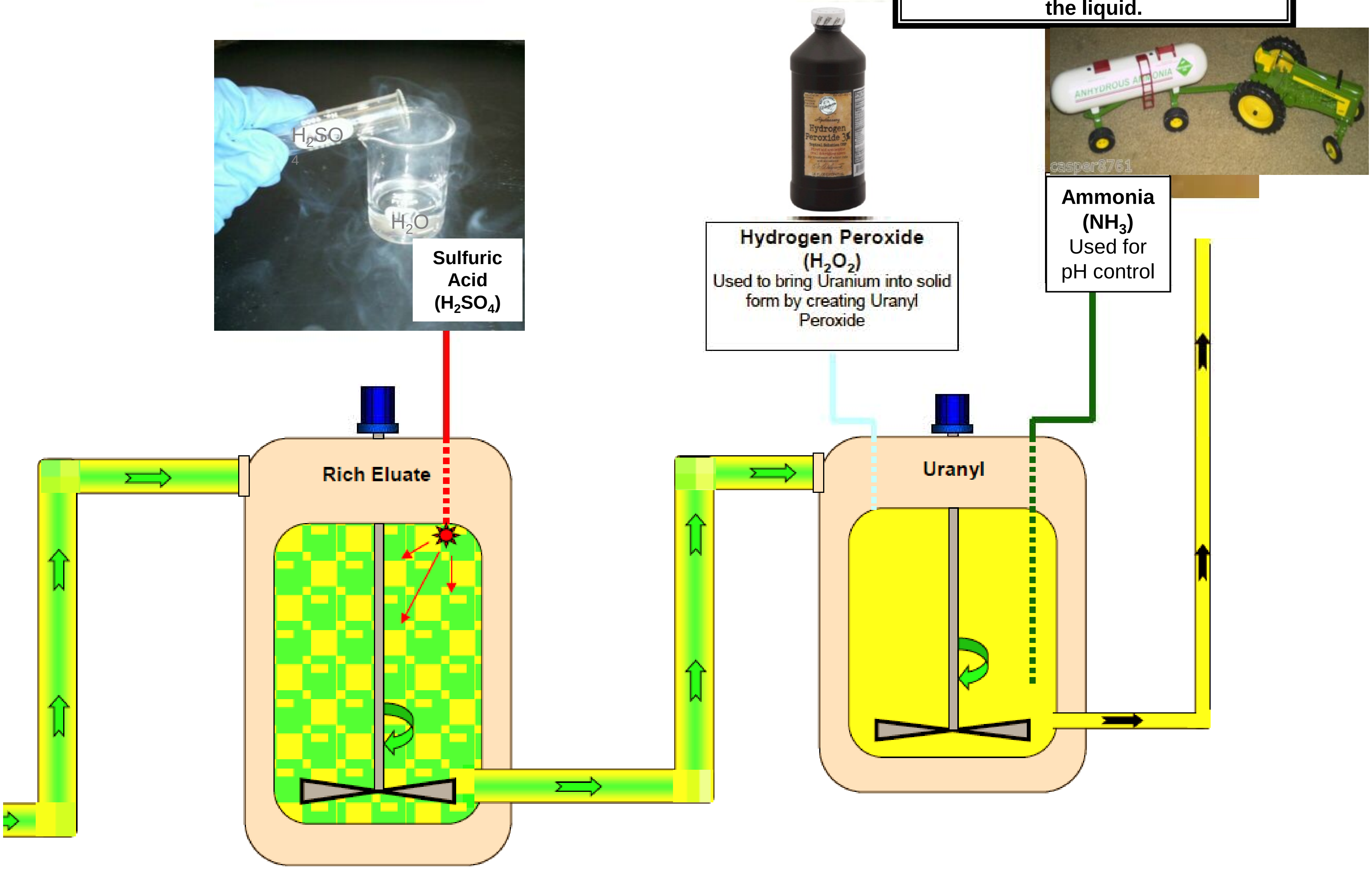
- The addition of hydrogen peroxide precipitates the uranium as uranyl peroxide.

$$U + 4H_2O_2 \rightarrow UO_4 + 4H_2O$$

- Next, soda or ammonia is added to neutralize any remaining acid.

Add Sulfuric Acid to eliminate Soda Ash

"Yellowcake Precipitation": A process where the uranium is made into a crystal form and settled out of the liquid.



Sulfuric Acid (H_2SO_4)

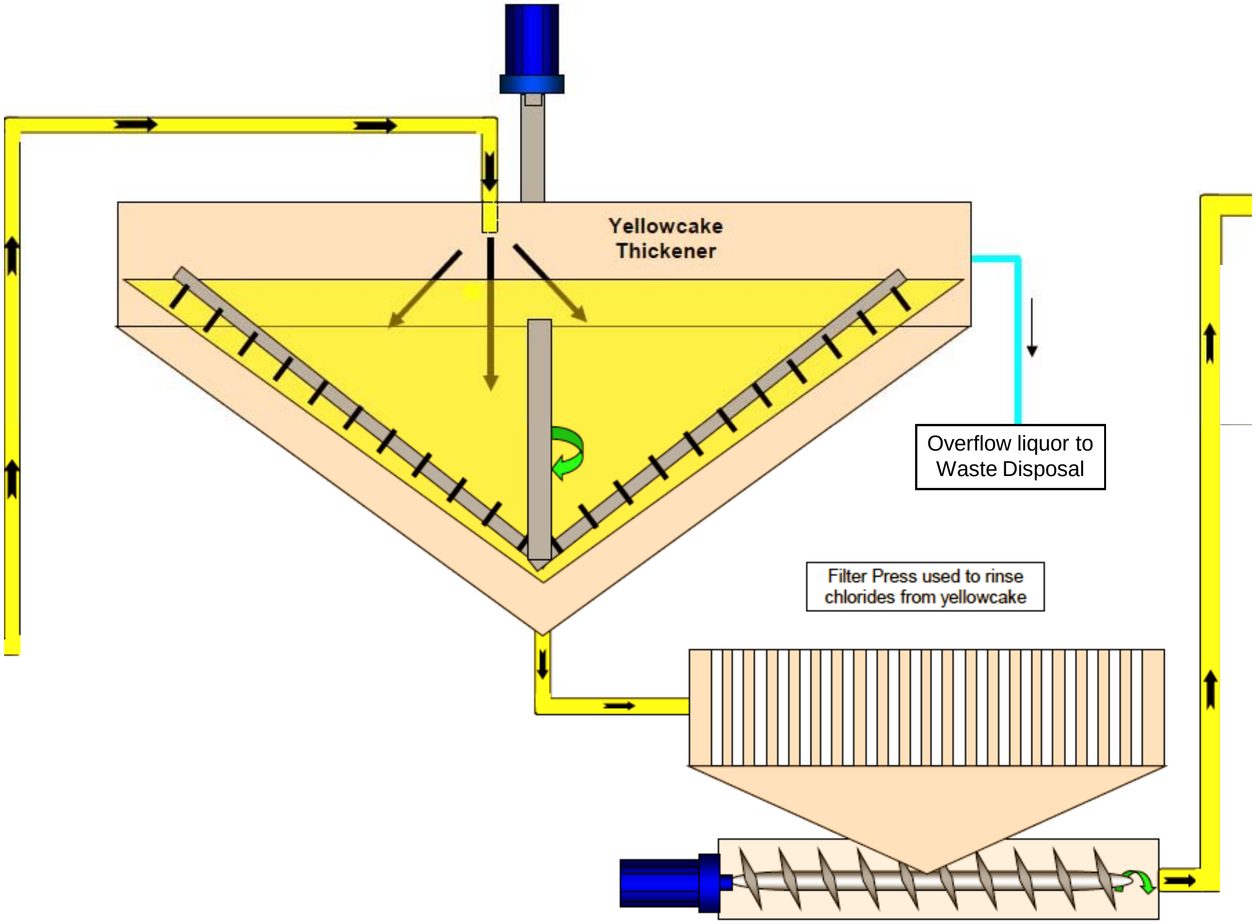
Hydrogen Peroxide (H_2O_2)
Used to bring Uranium into solid form by creating Uranyl Peroxide

Ammonia (NH_3)
Used for pH control

Settling and Washing of the Yellowcake

- A slurry containing the precipitated uranyl peroxide is transferred to a large conical tank, the thickener.
- From this point forward, uranium (especially airborne particulate) should be the primary radiological concern.
- The uranium, now referred to as yellowcake, settles out at the bottom of the thickener.
- After settling, the uranium is washed to remove the chlorides and filtered.
- A slurry of the yellowcake is then sent to the dryer.

Yellowcake thickener where the yellowcake crystal is given time to settle and grow.



Overflow liquor to Waste Disposal

Filter Press used to rinse chlorides from yellowcake


12

Drying of the Yellowcake

- Finally, the yellowcake is sent to the dryer.
- Older facilities dry the yellowcake at very high temperature (400 -650 °C) using multi-hearth gas fired dryers.
- An advantage of the multi-hearth dryers is that the high temperatures drive off any organic contaminants which might otherwise oxidize.
- A disadvantage is that the dryer exhaust will contain particulate uranium that must be removed.

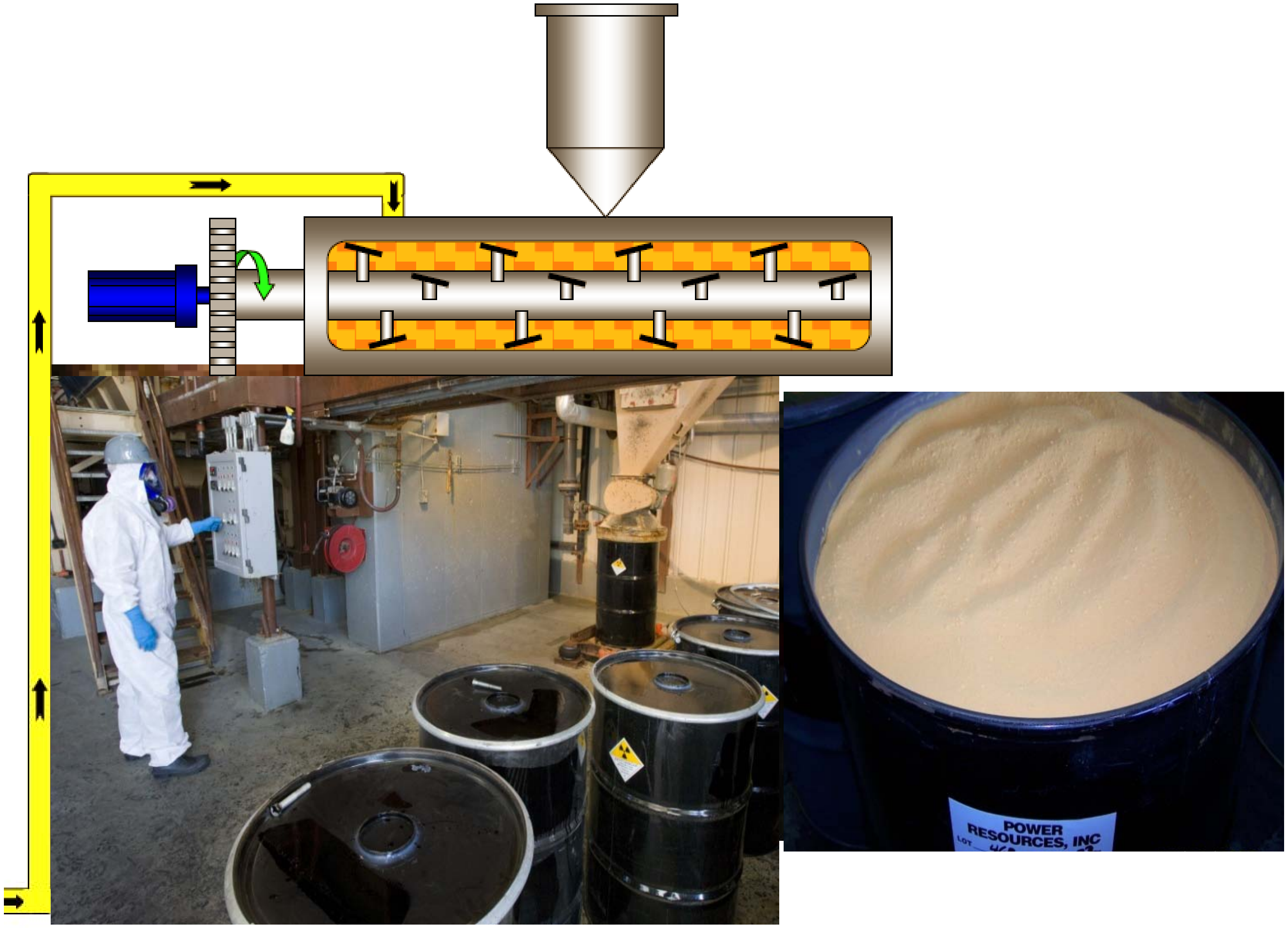
Drying of the Yellowcake

- **Newer facilities dry the yellowcake at low temperature (ca. 150 °C) using vacuum dryers.**

- **An advantage of the vacuum dryer is that its exhaust contains no radioactive material.**

- **Since the operation is conducted under negative pressure, there should be no escape of yellowcake fines into the room air.**

Yellowcake is dried in a rotary vacuum dryer into a powder and loaded into drums.




DRYER
A

Drumming of the Yellowcake

- The yellowcake is emptied from the bottom of the dryer into 55 gallon drums.

- During loading, the drum is kept under negative pressure with a suction system. The suction line air is run to a dust collector.

- The drum is not sealed until the yellowcake has cooled in order to prevent ruptures.

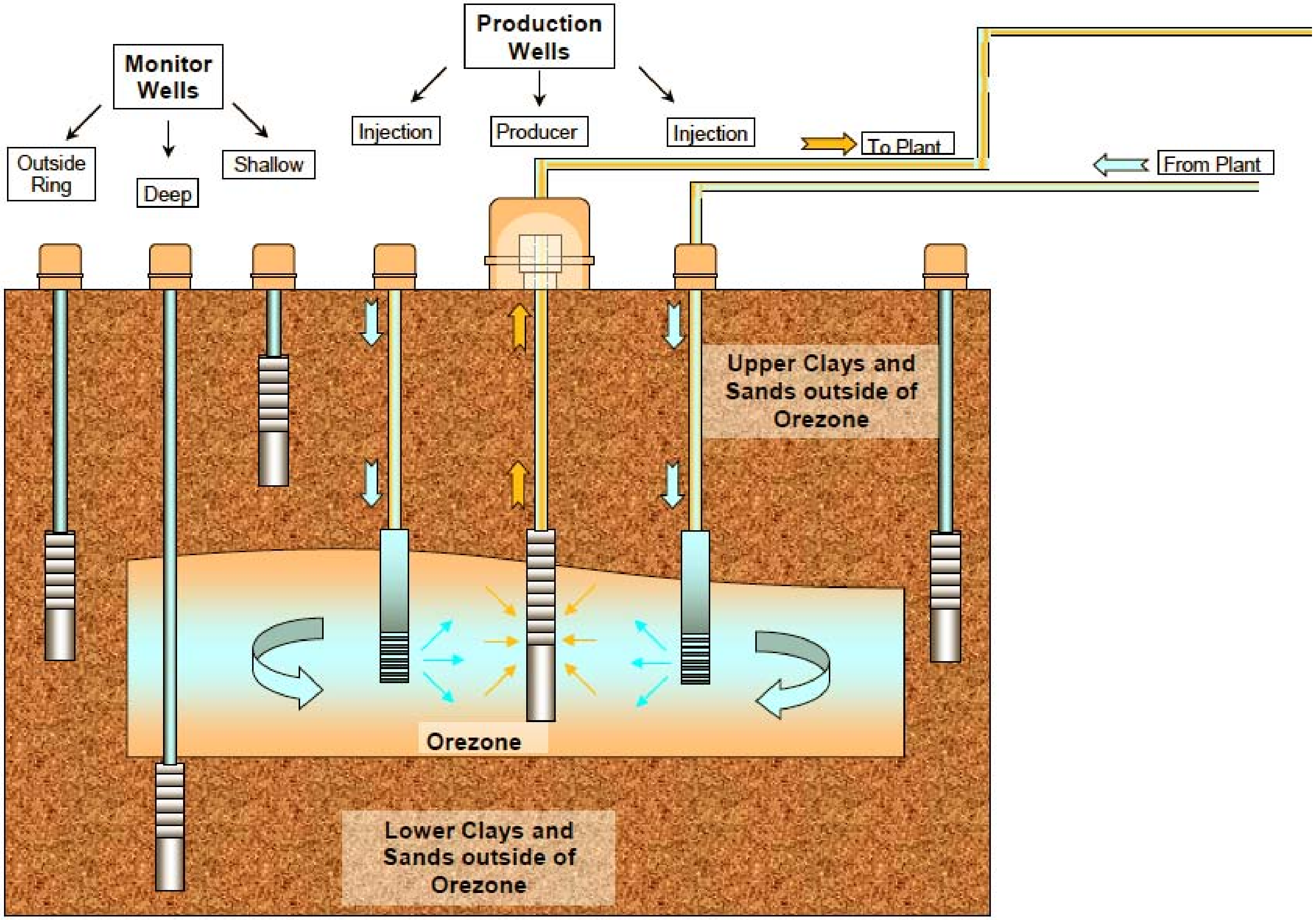

45
45

Loaded Trailer Ready for Shipment to Conversion Facility.

Groundwater Restoration

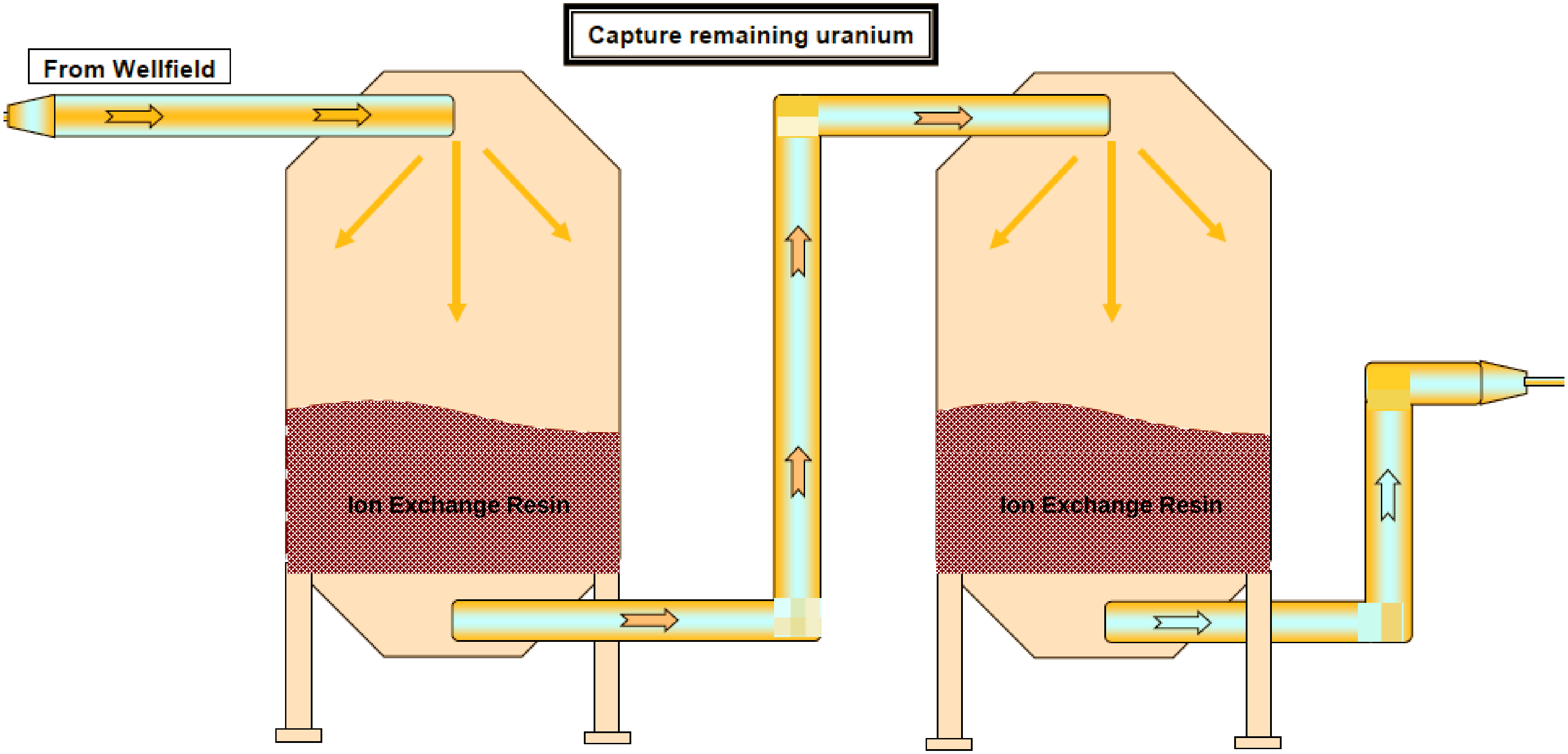
- Prior to uranium recovery operations beginning in a given area, the groundwater quality must be assessed with monitoring wells.
- After uranium recovery operations cease, the groundwater should be returned to its original state. Failing this, the next option would be to restore the water to conditions that do not exceed the EPA primary and secondary drinking water standards' limits.
- The contaminants of interest are those mobilized into the groundwater by the lixiviant.

RESTORATION: Restoring a Wellfield



Groundwater Restoration

- The restoration involves removing water from the well field, possibly without reinjection.
- Any remaining uranium in the groundwater might be removed via ion exchange.
- Afterwards, the water is rough filtered by sand and a cartridge filter. It is then run under pressure through a reverse osmosis unit. In some situations, the water might not require treatment via reverse osmosis.

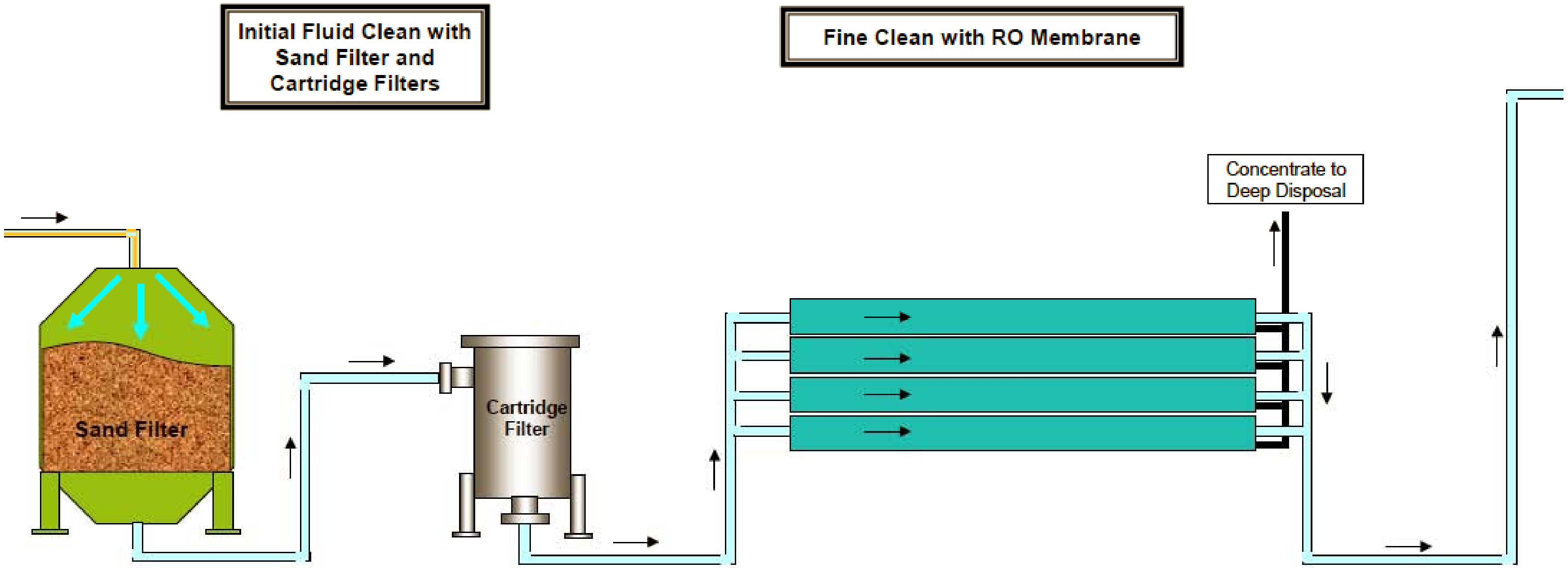


Capture remaining uranium

Groundwater Restoration

- The fluid stream produced via reverse osmosis that contains the concentrated mineral “contaminants,” is known as the brine. It might be:
    - sent to deep disposal wells, or
    - sent to a lined settling (aka evaporation) pond

Water in the settling ponds would be treated with barium chloride to precipitate the radium. The sludge containing the precipitated radium would be disposed of appropriately.


Initial Fluid Clean with Sand Filter and Cartridge Filters

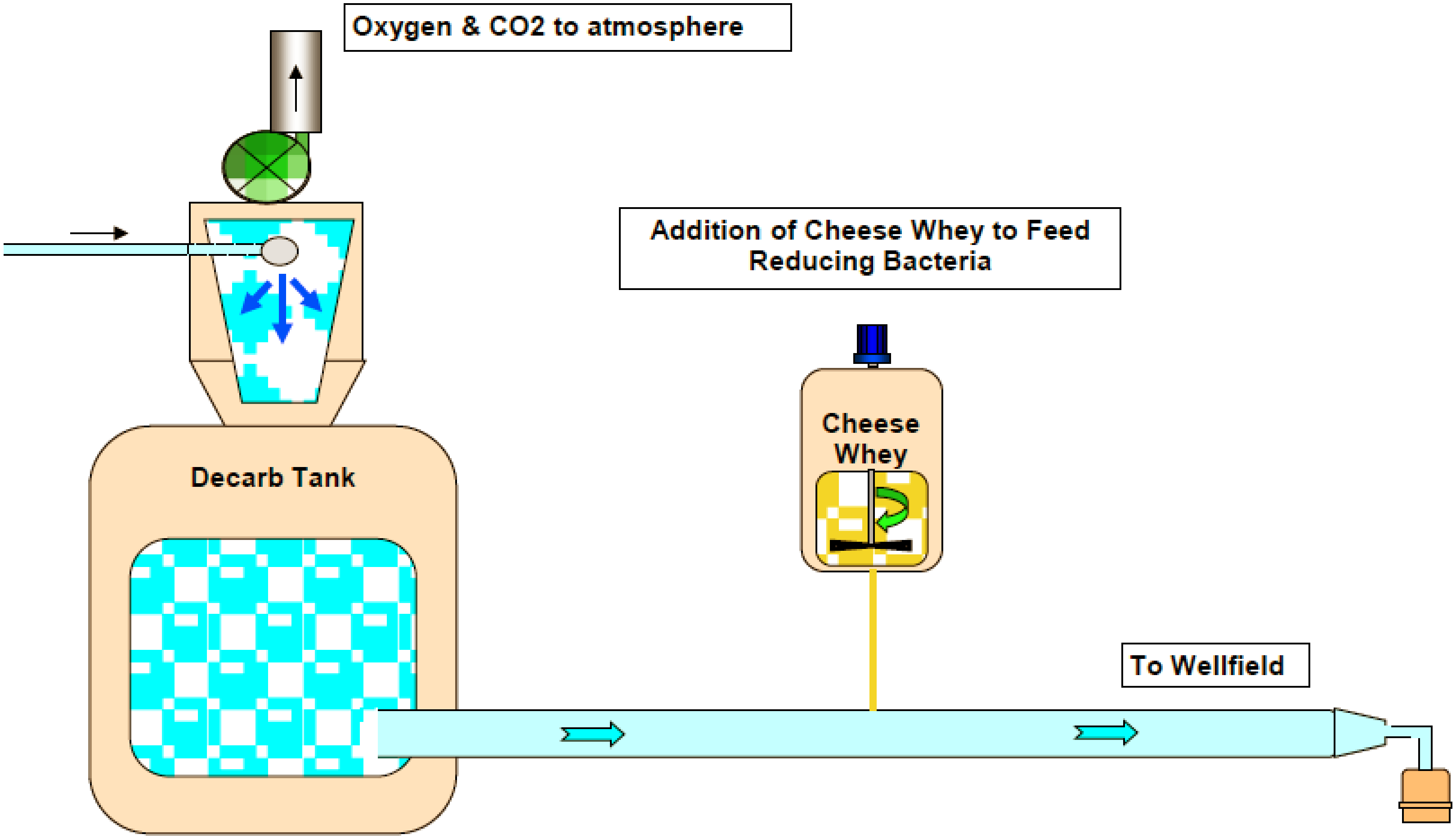
Fine Clean with RO Membrane

Concentrate to Deep Disposal


RADIATION AREA
R O line
R O line
R O line

Groundwater Restoration

- The fluid stream produced via reverse osmosis that consists of clean water is referred to as the permeate.
- After treatment, the permeate might be injected into the ground or employed for surface irrigation.
- The treatment might consist of the addition of reducing agents and/or food (e.g., cheese whey) that would supply nourishment for reducing bacteria.
- The goal of creating a reducing environment in the ground is to reverse the action of the lixiviant and precipitate the mobilized minerals.



Oxygen & CO2 to atmosphere

Addition of Cheese Whey to Feed
Reducing Bacteria

To Wellfield