Nuclear decommissioning: Turning waste into Wealth

The chemistry of cake

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  – impurities,
  – solvent extraction,
  – neutralisation,
  – precipitation.

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Yellowcake and its uses

Yellowcake refers to a substance produced after purification and concentration of uranium from ore, using acid leaching techniques and consists of ~80% triuranium octoxide (U₃O₈).

Impure uranium ore consists of UO₂, UO₃, U₃O₈ and impurities. Purification of uranium ore and extraction of U₃O₈ (yellowcake) comprise the first stage in the cycle that leads to reactor fuel.

Density: 9.6 g/m³ BP: 2878 °C
Yellowcake extraction 1

Uranium ore crushed & ground

Uranium leached with sulfuric acid

UO$_2$$(SO_4)_3$

Solvent extraction: amines in kerosene

$$(R_3NH)_4UO_2(SO_4)_3$$

Heating yields concentrated $U_3O_8$ (yellowcake)

$$(NH_4)_2U_2O_7$$

Ammonia added $\rightarrow$ oxidation, precipitation filtration

$$(NH_4)_4UO_2(SO_4)_3$$

Ammonium sulfate & vacuum evaporation removes solvents
Leaching

**Uranium ore crushed & ground**

Prior to leaching, the crushed ore is heated to ~750 °C to decompose compounds that could effervesce.

**Leaching with sulfuric acid (H₂SO₄):**

For the case of (amphoteric oxide) UO₃.

\[
\text{UO}_3(s) + 2\text{H}^+(aq) \rightarrow \text{UO}_2^{2+}(aq) + \text{H}_2\text{O} \\
\text{UO}_2^{2+}(aq) + 3\text{SO}_4^{2-}(aq) \rightarrow \text{UO}_2(\text{SO}_4)_3^{4-}(aq)
\]

**Pitchblende: UO₂, UO₃, U₂O₅**

Image credit: Geomartin via Wikimedia Commons (CC BY-SA 3.0)
Yellowcake extraction 2

Uranium ore crushed & ground

Uranium leached with sulfuric acid

UO₂(SO₄)₃

Solvent extraction: amines in kerosene

(R₃NH)₄UO₂(SO₄)₃

Ammonium sulfate & vacuum evaporation removes solvents

(NH₄)₄UO₂(SO₄)₃

Ammonia added → oxidation, precipitation filtration

(NH₄)₂U₂O₇

Heating yields concentrated U₃O₈ (yellowcake)
Solvent extraction

Solvent extraction with tertiary amines in kerosene (note phase change for UO$_2$):

$$2R_3N(\text{org}) + H_2SO_4 \rightarrow (R_3NH^+)_2SO_4$$

[R = alkyl grouping $\rightarrow C_nH_{2n+1}$]

$$2(R_3NH^+)_2SO_4^{2-}(\text{org}) + UO_2(SO_4)_3^{4-}(aq) \rightarrow$$

$$(R_3NH^+)_4UO_2(SO_4)_3^{4+}(\text{org}) + 2SO_4^{2-}(aq)$$

Loaded solvent is treated to remove impurities.

Impurities (e.g. silica, zirconates) stay in aqueous phase.
Yellowcake extraction 2

- Uranium ore crushed & ground
- Uranium leached with sulfuric acid
- Solvent extraction: amines in kerosene
  \[(R_3NH)_4UO_2(SO_4)_3\]
  \[(NH_4)_4UO_2(SO_4)_3\]

- Heating yields concentrated \(U_3O_8\) (yellowcake)
- Ammonia added → oxidation, precipitation filtration
  \[(NH_4)_2U_2O_7\]
- Ammonium sulfate & vacuum evaporation removes solvents
  \((NH_4)_2U_2O_7\)
Precipitation & oxidation 1

Addition of ammonium sulfate followed by heating removes solvents:

\[(R_3NH^+)_4UO_2(SO_4)_3^{4-}(\text{org}) + 2(NH_4)_2SO_4(\text{aq}) \rightarrow 4R_3N(\text{org}) + (NH_4)_4UO_2(SO_4)_3(\text{aq}) + 2H_2SO_4(\text{aq})\]

Return of acid and amine.
Precipitation & oxidation 2

Ammonia added → oxidation, precipitation filtration

Precipitation of \((\text{NH}_4)_2\text{U}_2\text{O}_7\) using gaseous ammonia:

\[
6\text{NH}_3(\text{g}) + 2\text{UO}_2(\text{SO}_4)_3^{4-} + 3\text{H}_2\text{O} \rightarrow (\text{NH}_4)_2\text{U}_2\text{O}_7(\text{s}) + 2(\text{NH}_4)_2\text{SO}_4
\]

Return of ammonium sulfate.

Heating yields concentrated \(\text{U}_3\text{O}_8\) (yellowcake)

Heating ammonium diuranate precipitate, \((\text{NH}_4)_2\text{U}_2\text{O}_7\), produces \(\text{U}_3\text{O}_8\) (yellowcake).
Yellowcake summary

Additional purification steps before leaching include:

- NaCl followed by heating to convert silver to silver chloride.
- Addition of NaNO₃ to oxidise UO₂ to UO₃.

Yellowcake is the starting point for UF₆ production:

- UF₆ is used to enrich content of ²³⁵U.
- UF₆ can be converted to UO₂ e.g. for AGR/CANDU (reactor fuel).
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Sources/further reading

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Bibliography 2

Sources/further reading

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• Contents page image from the Uranium Information Center