610-280 Environmental Chemistry

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Energy: Nuclear Fuel

- Nuclear Fuel Cycle
- Nuclear power world wide
- Operation of Nuclear Power Reactor
- Waste management

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References

- Baird, C. and Cann M. Environmental Chemistry, 3rd Ed., 2005
- Wright, J. Environmental Chemistry, 2003
- www.wise-uranium.org
- www.uic.com.au
- www.wikipedia.org
- Switkowski Report

Nuclear Energy

- Energy obtained from atomic nuclei
- Used mainly to produce electricity
- Two process to obtain energy
  - Fission – collision of certain heavy nuclei and neutron, resulting in splitting of nucleus into similar sized fragments.
  - Fusion – combination of two very light nuclei to form one combined nucleus

Nuclear fuel cycle

- Mining/milling
- Conversion
- Enrichment
- Reactor
- Reprocessing
- Waste

Mining

- Australia - worlds largest uranium reserves (> 30 % of known resources).
- Over half of worlds production of Uranium via mining is from Canada (28 %) and Australia (23 %).
- In 2005 Australia supplied 9519 tonne of uranium, mainly for export (world total mined 41 595 tonne). Value ~ $500 million
- Mined underground > open pit > in-situ leach > by-product.
- Grade of U_3O_8 0.04-0.5 % or 400 to 5000 ppm.

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Uranium extraction process

Milling Process

- Ore crushed and ground
- U leached using sulfuric acid

$UO_3(s) + 2H^+(aq) \rightarrow UO_2^{2+}(aq) + H_2O$

$UO_2^{2+}(aq) + 3SO_4^{2-}(aq) \rightarrow UO_2(SO_4)_3^{4-}(aq)$

- Concentrate – solvent extraction

$2R_3N(org) + H_2SO_4(aq) \rightarrow (R_3NH)_2SO_4(org)$

$2(R_3NH)_2SO_4(org) + UO_2(SO_4)_3^{4-}(aq) \rightarrow (R_3NH)_4UO_2(SO_4)_3(org) + 2SO_4^{2-}(aq)$

- Precipitate $(NH_4)_2U_2O_7$
- Heat to form U_3O_8

Conversion

- U_3O_8 dissolved in nitric acid, $UO_2(NO_3)_2.6H_2O$ heated to pure UO_3
- Reduce in kiln by hydrogen to UO_2

$UO_3 + H_2 \rightarrow UO_2 + H_2O$

- React with gaseous HF in another kiln

$UO_2 + 4HF \rightarrow UF_4 + 2H_2O$

- Fed into fluidised bed reactor with gaseous fluorine

$UF_4 + F_2 \rightarrow UF_6(g)$

- Ready for enrichment

Enrichment

- Cannot use chemical techniques as uranium-235 and uranium-238 are “chemically” identical
- Require technique that differentiates mass – eg centrifugation
- Once enriched converted to UO_2 and compacted into pellets and sealed in a corrosion resistant metal alloy - the Fuel Rod.
- Fuel rods generally placed in bundles.

Mined material to uranium fuel?

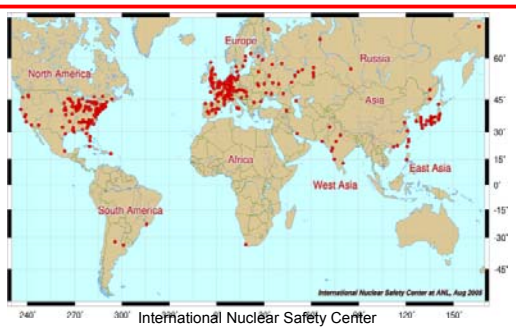
World Nuclear Power Reactors

NPR in operation (capacity 372 GW)

Country	No. of NPRs	Net output ($x10^3$ MW)
USA	104	100.3
France	59	63.3
Japan	55	47.6
Russia	31	21.7

http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm

World map NPR



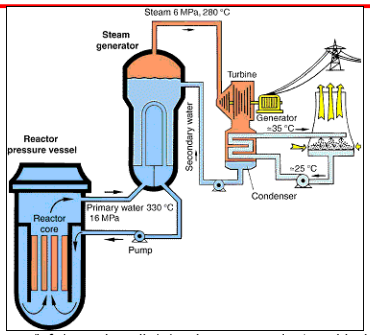
International Nuclear Safety Center
http://www.insc.anl.gov/pwrmaps/map/world_map.php

Types of NPR

- Boiling Water Reactor
- Pressurized Water Reactor
- Gas Cooled Fast Reactor
- Liquid Metal Cooled Reactor
- Fast Breed Reactor
- Molten Salt Reactor
- …..

Operation of NPR

Pressurised water reactor (PWR)



http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm

Types of Waste

- Exempt or very low level waste – not considered harmful
- Low level waste (LLW) – small amounts of short-lived radioactivity, doesn't require shielding, gen. incinerated and deposited in shallow land burial
- Intermediate level waste – solidified in concrete
- High level waste (HLW) – fission products, highly radioactive and hot, requires shielding and cooling

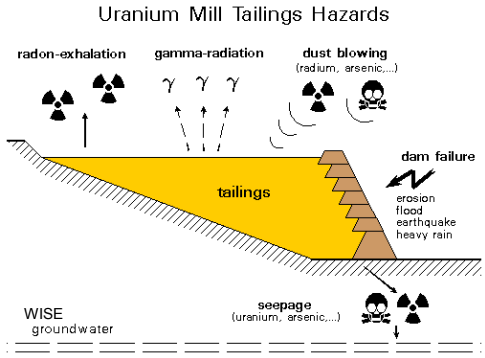
Waste disposal

Three general principles applied to waste:

- Concentrate and contain
- Dilute and disperse
- Delay and decay

- Mining – tailings dams – covered with clay or water.
- Conversion & enrichment – depleted U.
- Reactor – fission products in the spent fuel HLW – initially stored in cooling ponds, then can be reprocessed or encapsulated for disposal – buried in dry, geologically stable areas

Tailings



Waste immobilisation

- Waste must be stabilized – not able to react, degrade, leach, …
- Vitrification: waste is calcined, forming solid nitrates or oxides, mixed with components of borosilicate glass (80 % SiO_2, B_2O_3, Al_2O_3 and Na_2O), poured into canisters (1.3 m x 0.4 m diam, 400 kg glass).
- Synroc: waste incorporated into the crystalline structure of the “synthetic rock” comprising hollandite ($BaAl_2Ti_6O_{16}$), zirconolite ($CaZrTi_2O_7$) and perovskite ($CaTiO_3$). Can be tailored for specific HLW components.

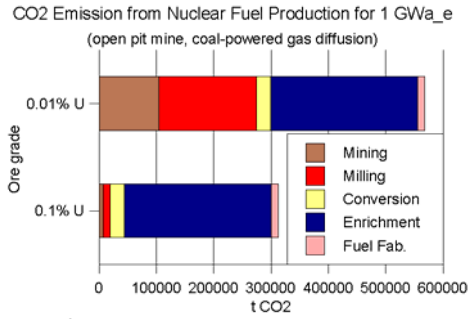
Long term disposal

- Geological disposal – deep underground
  - Low population density
  - Stability – preventing contamination of groundwater
  - Intrusion proof

On July 18, 2006 the DOE agreed upon March 31, 2017 as the date to open the Yucca Mountain facility and begin accepting waste.

Wikipedia

No CO_2?



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In summary

Lecture 12: Nuclear Fuel

- Discussed chemistry involved at various stages of nuclear fuel cycle
- Understood the working mechanism of a pressurised water nuclear power reactor
- Waste management