610-280 Environmental Chemistry

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Energy: Nuclear Fuel – Environmental Impact

- Accidents
- Specific radionuclides
- Radionuclides in the environment
- Ionising radiation and health

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References

- www.epa.gov/radiation/radionuclides

Accidents in the past

- Three Mile Island, 1979
- Chernobyl, 1986
- Japan, 1999

  $Zr(l) + 2H_2O(g) \rightarrow ZrO_2(s) + H_2(g)$

  $C(s) + O_2(g) \rightarrow CO_2(g)$

  $2C(s) + O_2(g) \rightarrow 2CO(g)$
- Some of the radionuclides dispersed into the environment:

  ^{90}Sr, ^{131}I, ^{137}Cs, Pu

Strontium (Sr)

- Sr has four stable, naturally occurring isotopes: ^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr.
- U and Pu fission produce many isotopes of Sr, but the most significant, because of its long half-life, is ^{90}Sr.
- ^{90}Sr ($t_{1/2}$=29.1 y) beta decays into strongly radioactive ^{90}Y ($t_{1/2}$=64 h), which in turn beta decays to become stable Zr.
- Sr forms many chemical compounds: halides, oxides, and sulfides, moving easily through the environment.
- Sr is referred to as a “bone seeker” because it replaces Ca in bones and teeth, leading to bone cancer, leukemia and cancer in the soft-tissue contacting bone. Sr is mostly introduced to the body through ingestion.

Iodine (I)

- ^{127}I is iodine’s only natural isotope
- U and Pu fission produce ^{129}I ($t_{1/2}$ = 15.7 million years) and ^{131}I ($t_{1/2}$ = 8.07 days). Usually released as a gas.
- ^{131}I emits beta particles and gamma rays transforming to ^{131}Xe.
- Iodine can disperse rapidly in air and water. Combines with organic matter in soil.
- It concentrates in the thyroid gland.

Cesium (Cs)

- Cs has one naturally occurring isotope, ^{139}Cs.
- U and Pu fission produce many isotopes of Cs, but the most significant is ^{137}Cs ($t_{1/2}$=30.2 y).
- ^{137}Cs emits beta particles and gamma rays, decaying into ^{137}Ba, which decays again to stable forms of barium.
- Cs absorbs readily into solution, mp of 28 C
- Radioactive Cs is evenly dispersed through out the body. Cs is mostly introduced to the body through contact with contaminated water and soils.

Plutonium (Pu)

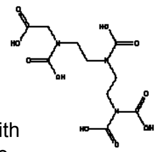
- Trace amounts naturally occurring
- U fission produces common isotopes 238Pu ($t_{1/2}$= 87.7 y), 239Pu ($t_{1/2}$= 24 100 y) and 240Pu ($t_{1/2}$=6560 y).
- 238Pu alpha decays to 234U, 239Pu alpha decays to 235U
- Pu in air, water, soil
- Inhalation resulting in absorption into bloodstream then on to bones, liver, …

Nuclear fallout

- Strontium
  - Enters food chain/water supply
  - Similar to calcium (undergo ion exchange), bone seeking element
  - Can cause bone tumours, bone cancer and leukaemia
- Iodine
  - Water supplies, crop
  - Concentrates in the thyroid
- Cesium
  - Enters food chain/water
  - Widely distributed in muscle tissue
- Plutonium
  - Strongly sorbed by soil, relatively immobile
  - PuO_2^{2+} ion, is bone seeking

Actinide reactivity

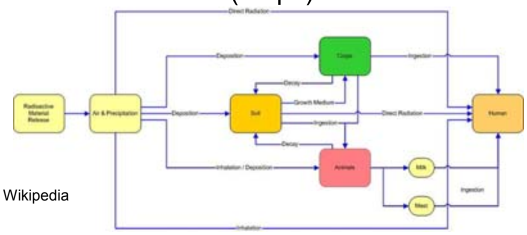
The actinides readily form dioxides. The actinide dioxide core readily complexes with oxygen moieties (carbonates, alcohols, nitrites, nitrates, sulfates, phosphates, etc.), forming anionic species that are readily mobile in the environment.



Actinide poisoned humans can be treated with the calcium or zinc salt of diethylene triamine pentaacetic acid (DTPA). DTPA chelates the heavy metal ion, making digestive absorption impossible, and allowing it to be quickly excreted.

Radionuclides and the environment

- Atmosphere (humans, animals, crops)
- Water (humans, animals, aquatic animals/plants, crops)
- Rocks and soils (crops)



Wikipedia

Radiation units

- Radiation activity
  - Becquerel (Bq) – number of decays per second (measured using a Geiger counter)
- Radiation exposure
  - Gray (Gy) – absorbed dose – energy deposited in kg of material (1Gy = 1 J energy absorbed in 1 kg material)
  - Sievert (Sv) – equivalent dose – takes in to account the radiation weighting factor (= 1 for β-particles and γ-rays and = 20 for α-particles)
  - Sievert (Sv) – effective dose equivalent – also takes in to account the tissue type

Radioactivity of

	Radioactivity (Bq)
1 kg coffee	1000
Air in 100 m^2 house	3000
Adult	~4000
Smoke detector (Am)	30 000
1 kg U ore (Aust)	500 000
1 kg 50 y.o. vitrified HLW	10 000 000 million

Radiation absorbed by humans

Average annual radiation (UK)

	Percent
Radon	51
Buildings/soils	14
Food and drink	12
Medical	12
Cosmic rays	10
other	1

Radiation levels

- 10 Sv short term/whole body dose – immediate illness, death within a few weeks
- 2-10 Sv short term – severe and sickness, increasing likelihood of fatality
- 1 Sv short term – immediate radn sickness
- 0.1 Sv probability of cancer increases with dose
- 0.05 Sv – lowest dose at which there is evidence of cancer caused
- 0.02 Sv/yr limit for employees in nuclear industry
- 0.002 Sv/yr typical background irradiation from natural sources

Ionising radiation - health

- In biological tissue radiation generally results in ionization of water:
  H_2O + radiation → e^- + $H_2O^{\cdot +}$
  H_2O + radiation → H_2O^*
- Further reaction to form radicals
  - unpaired electron, highly reactive, neutral or charged
  $H_2O^{\cdot +} \rightarrow H^+ + {}^{\cdot}OH$
  $H_2O^* \rightarrow H^{\cdot} + {}^{\cdot}OH$
  $H^+ + e^- \rightarrow H^{\cdot}$
  ${}^{\cdot}OH + {}^{\cdot}OH \rightarrow H_2O_2$

Ionising radiation - health

- In biological matter
  - Direct action – ionisation or excitation inducing radical formation in biological molecule
  - Indirect action – ionisation of solvent molecules as intermediaries.
- Radiation damage in DNA can be repaired e.g.. by recombination or restitution
- O_2 reacts with DNA making damage harder to repair
- Ionised DNA and protein molecules no longer function as they should, can result in cancer and radiation sickness.
- Long term effect – genetic damage

In summary

Energy: Nuclear Fuel – Environmental Impact

- Past accidents and influence on future
- ^{90}Sr, ^{131}I, ^{137}Cs, Pu
- Radionuclides in the environment
- Radiation Chemistry and radiation damage to human health