Background to post-closure safety assessment

Content

- Discuss post-closure SA in general
- Basis of post-closure safety for BOSS

RWM Principles

- Protection of future generations
- Burden on future generations
- Disposal aims to comply with both of these through
  - *isolation* and
  - *confinement*
- Safety assessment is the tool used to demonstrate safety and its robustness

Safety Functions

- **Isolation** of the waste
  - avoids releases due to inadvertent human intrusion through depth & choice of site
- **Containment** of radionuclides in the waste
  - avoids/ reduces release into the human environment
  - based on physical and chemical processes

Disposal at depth

Provides

- Stability - chemical, physical, political
- Disposal at depth promotes both
  - Isolation (HI/ security)
  - Containment (natural releases)

Isolation

Human Intrusion

- depth >30 m below local topography
  - limits intrusion to exploratory drilling
- deflector plate
  - reduces significance of drilling
- avoid potential resources
- small footprint
- removal of casing
- native soil at top 2m

} reduce probability of intrusion

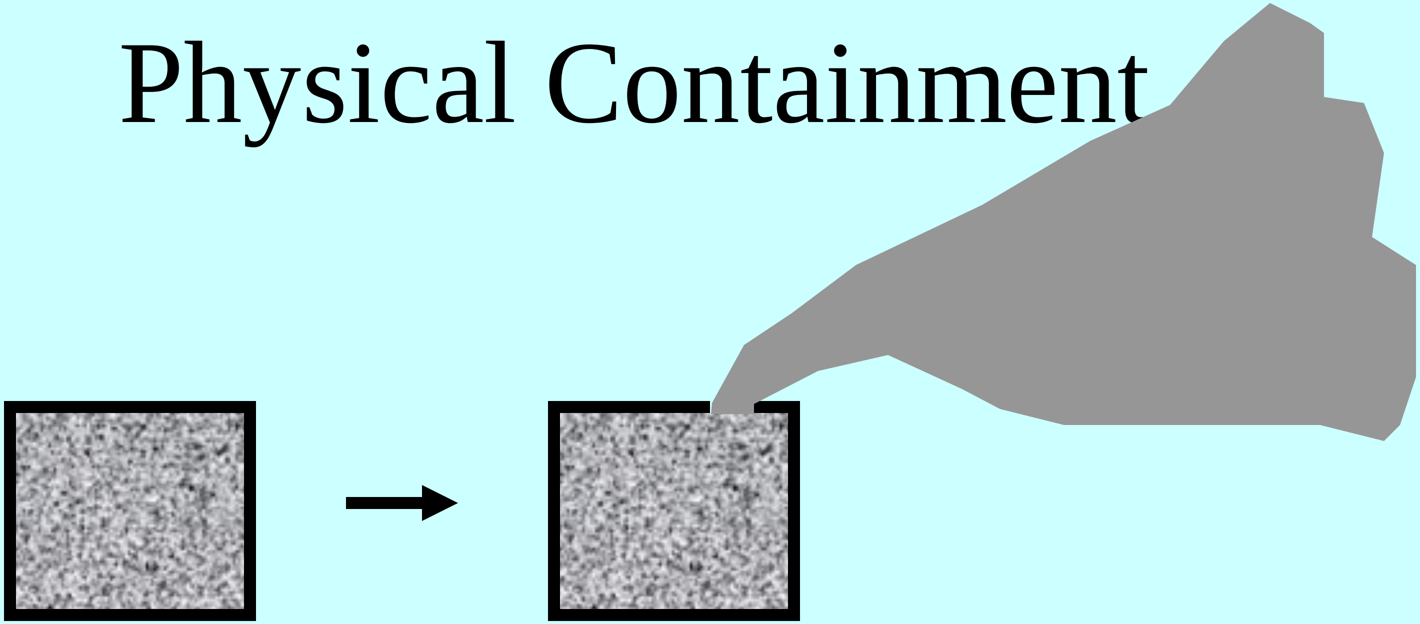
Human Intrusion

"*The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent intrusion*" US EPA

"Because the occurrence of human intrusion cannot be totally ruled out, the consequences of one or more typical plausible stylised intrusion scenarios should be considered by the decision-maker to evaluate the resilience of the repository to potential intrusion" ICRP81

In the GSA, human intrusion is modelled by assuming an exploratory drilling close to, or even into, the disposal

Physical Containment



– aim to physically contain the radionuclides for long enough for them to decay - 10 half lives gives a reduction in activity of 1000 (ie 2^{10})
– depends of the corrosion rate of the container and capsule

Contaminant transport

Two mechanisms:

Advection (also called convention)

driven by groundwater flow

expressed by Darcy’s Law

Diffusion

driven by concentration gradients

expressed by Fick’s Laws

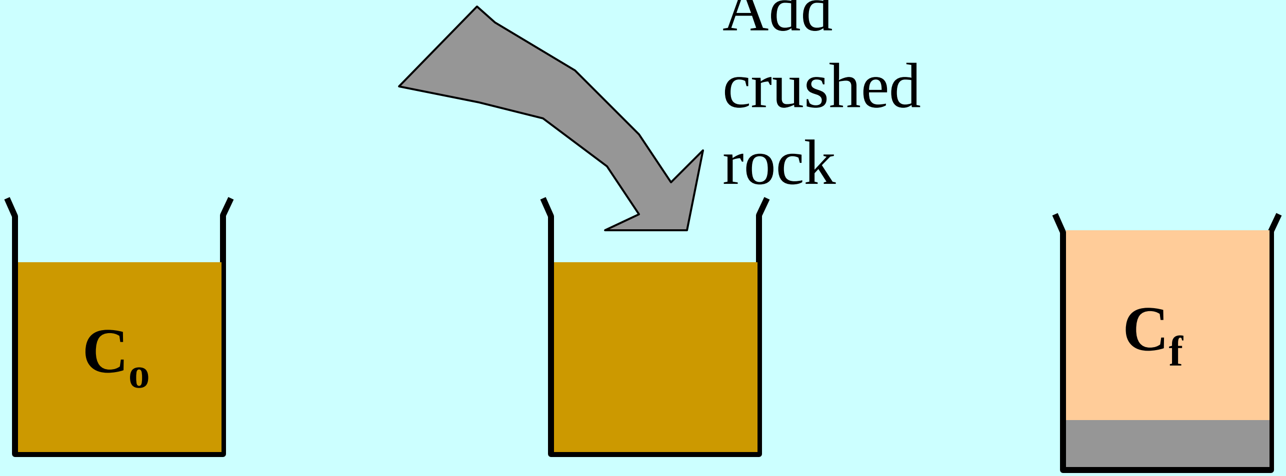
Chemical Containment

- Has two components
  - solubility limitation
  - sorption

Solubility limitation

- Based on
  - high pH reduces solubility of actinides
  - low redox potential induces lower valency speciation (eg U^{4+} rather than U^{6+})
- But pH falls over time as hydroxyl ions are washed out of the concrete. Solubility limitation is ignored in the GSA (conservative assumption)

Sorption Experiment

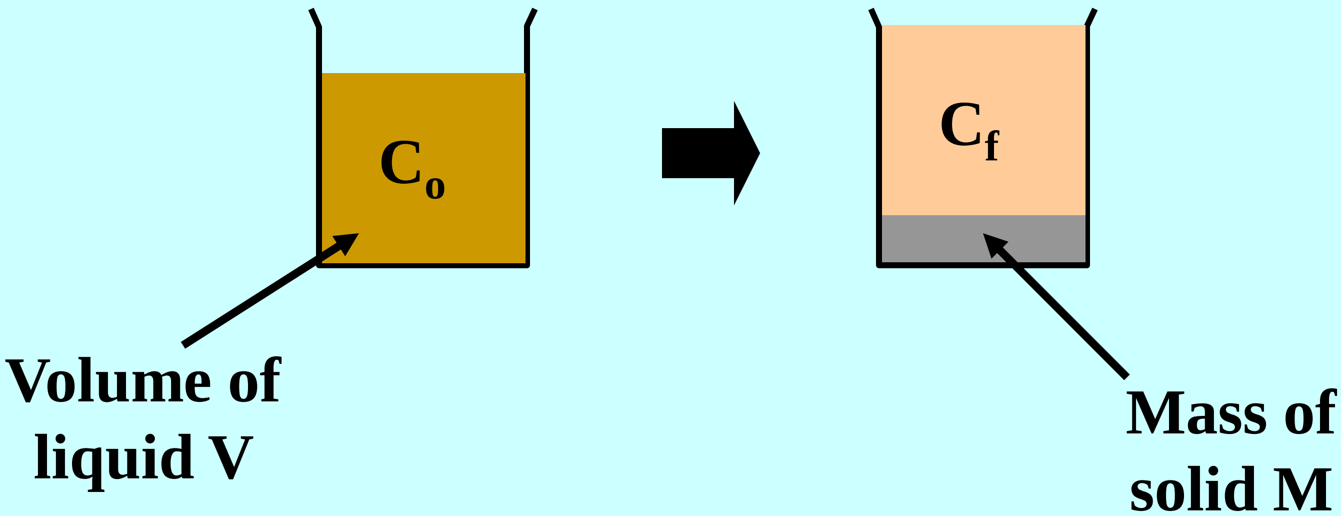


$C_o >> C_f$

Sorption

- Sorption is a catch-all term that includes
  - ion exchange reactions
  - absorption
  - adsorption
  - not chemical reaction (unless unknowingly)
- chemically reversible

Sorption (or partition) coefficient

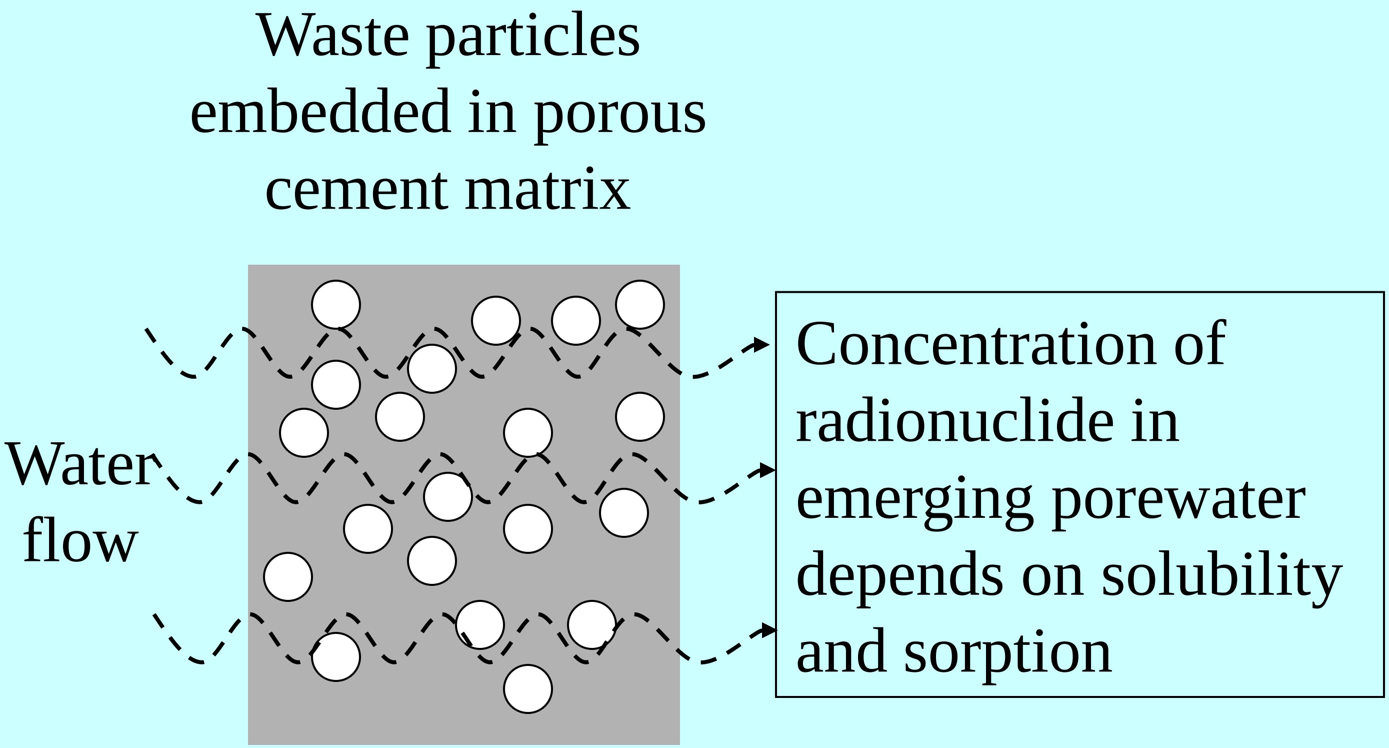


$$Kd = \frac{\text{amount sorbed to solid}}{\text{amount in solution}}$$

$$Kd = \frac{(C_o - C_f)V}{C_f M}$$

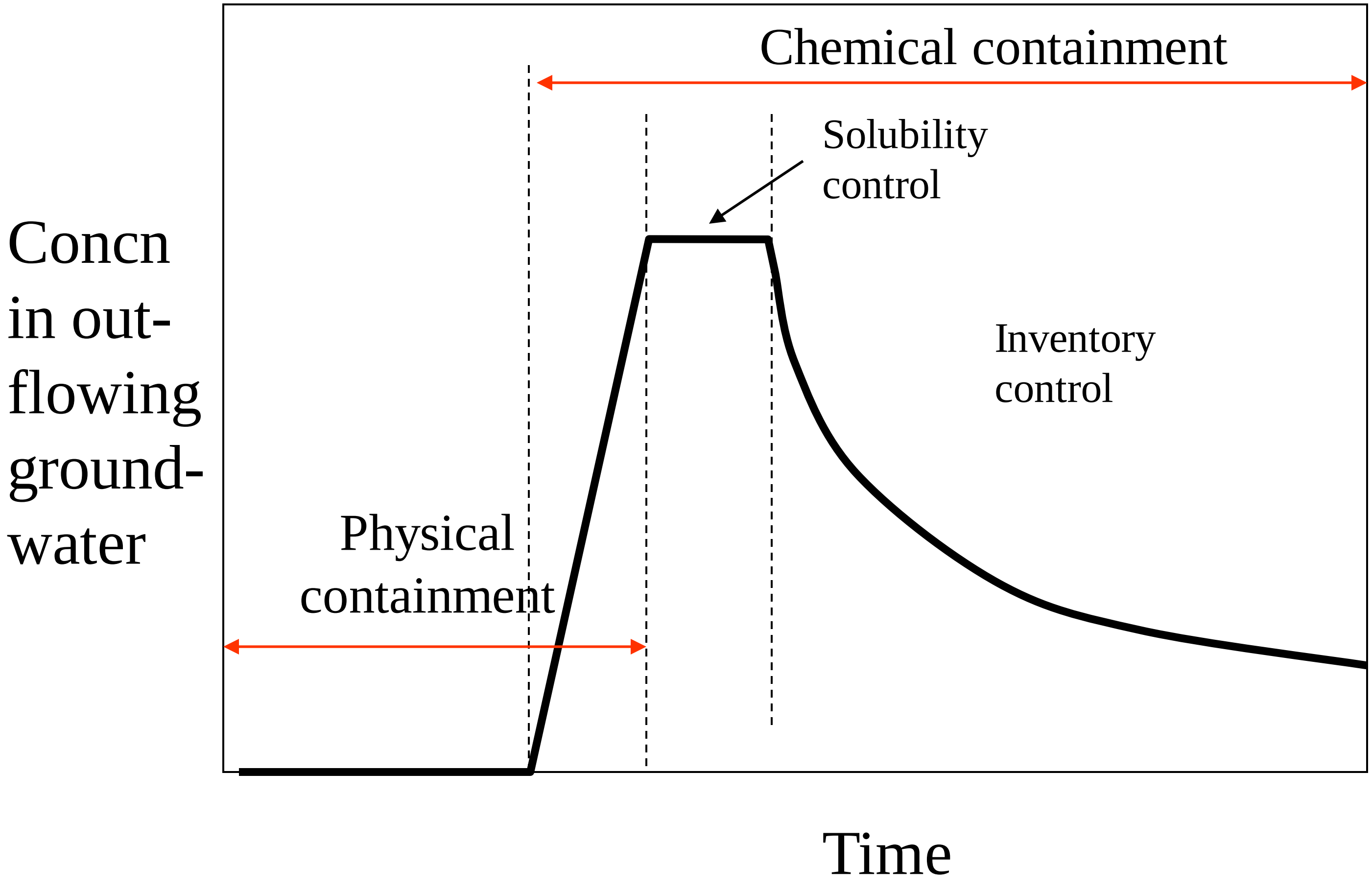
Has units of V/M

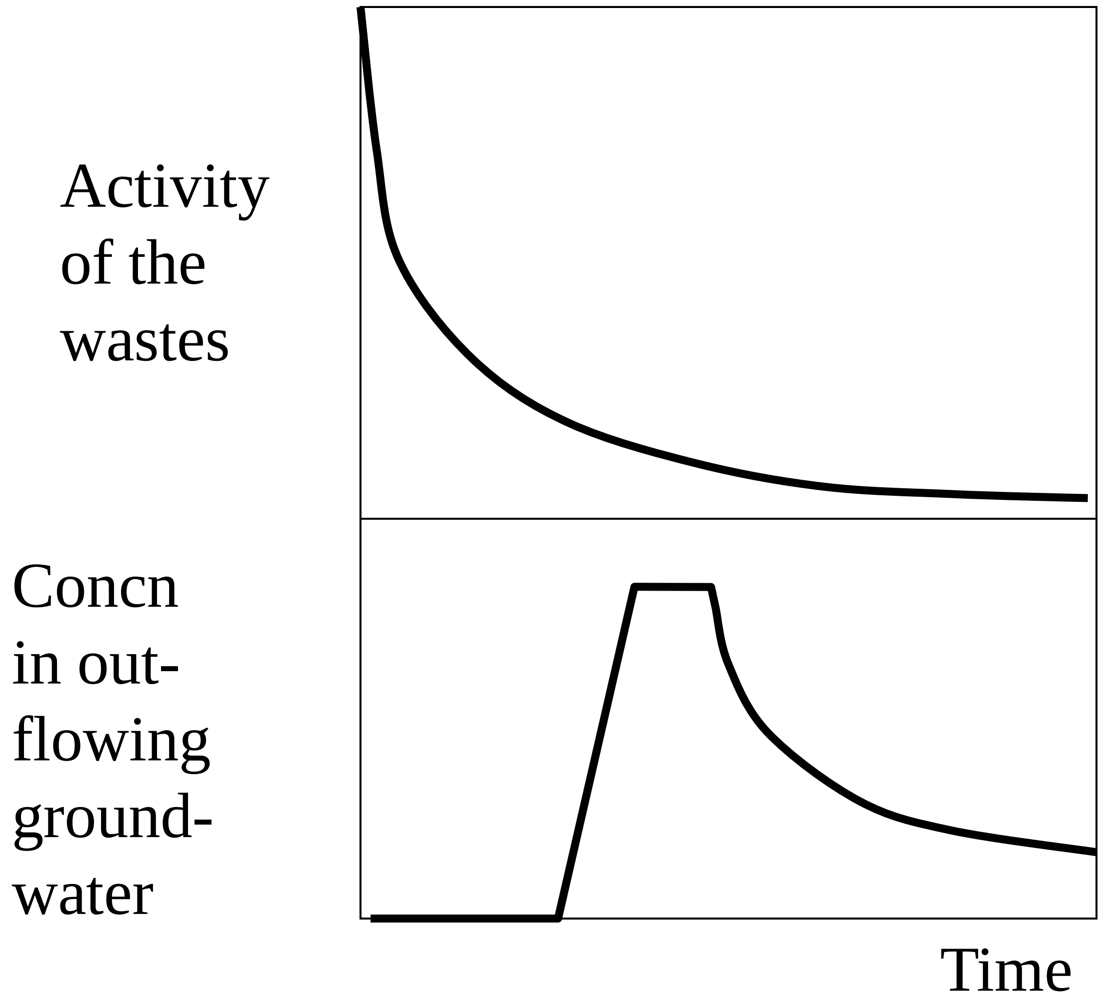
Chemical containment example



Can be expressed mathematically = source term

Near-field source term




Activity
of the
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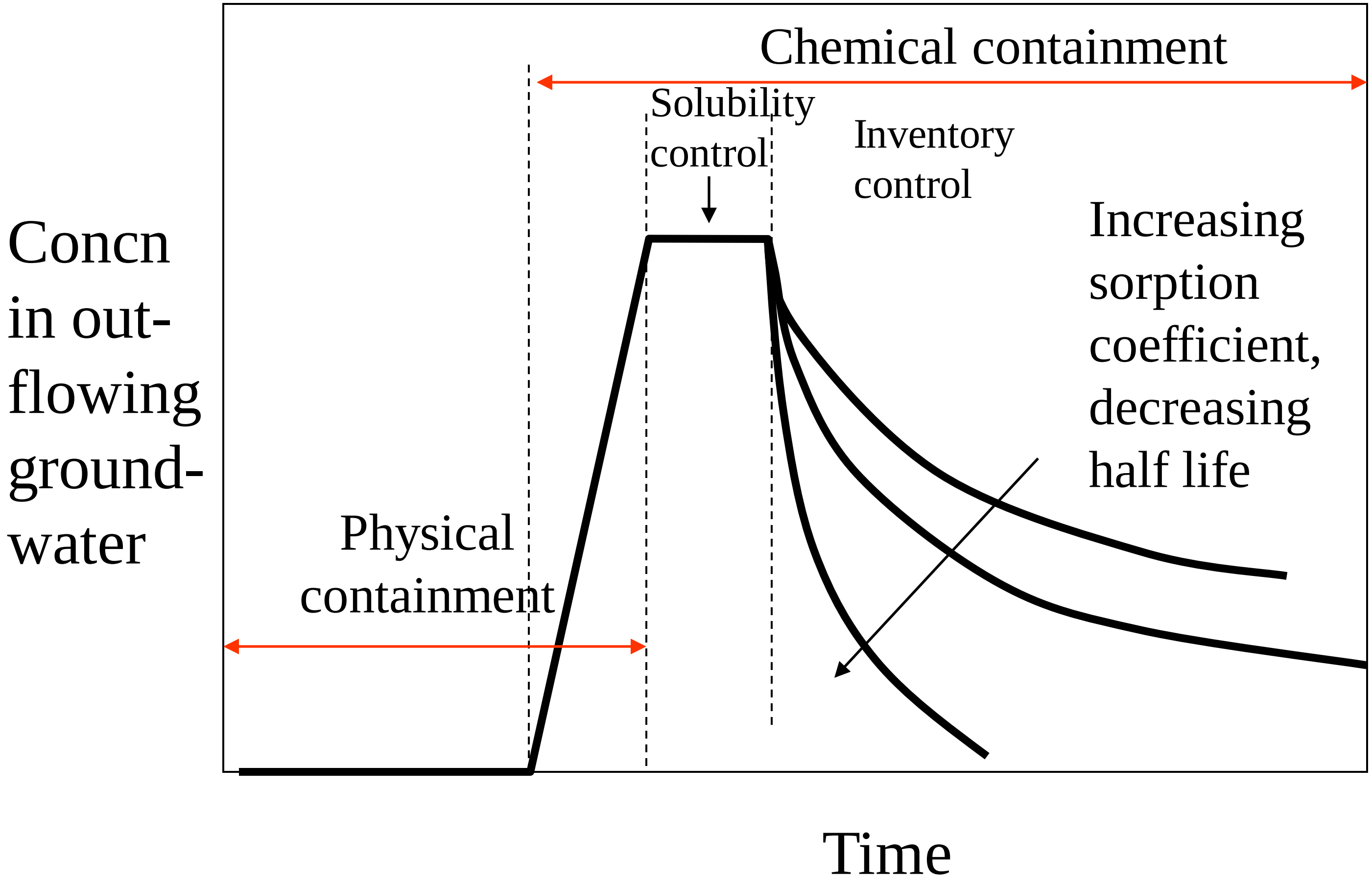
water
Time

Near-field source term



Chemical containment

- Most difficult radionuclides to contain are
  - long-lived
  - high solubility
  - low sorption
- eg I-129, Cl-36, Ra-226

Chemical containment

Some comparisons from Nirex95

	Half life	**Solubility at pH 10 mole/m^3**	**Kd m^3/kg**
I-129	15.7 Ma	Unlimited	6 E-4
Ra-226	1600 a	Unlimited	0.37
U-234	244,000 a	3 E-3	19
Pu-238	88 a	1 E-7	0.8
Np-237	2.1 Ma	6 E-6	70
Am-241	432	2 E-7	25

Implications of sorption coefficient

$$Kd = \frac{amount\ sorbed\ to\ solid}{amount\ in\ solution}$$

$$1 + Kd = \frac{amount\ in\ solution + amount\ sorbed\ to\ solid}{amount\ in\ solution}$$

$$1 + Kd = \frac{total\ amount\ of\ contam'nant}{amount\ in\ solution}$$

K_d = 99 means that, at any time, 1% of the total amount of contaminant is in solution. The remainder is sorbed

Containment: summary

Two type of containment:

- Physical
  - Absolute
  - Partial
- Chemical
  - Solubility control
  - Inventory control

Overall aim is to retard the movement of radionuclides so that they will decay in-situ

BOSS post-closure safety

Natural releases

- long-term safety rests on physical containment in near field
  - importance of geochemistry
- then chemical containment in near field
  - sorption on concrete
- then non-engineered barriers
  - retardation in geosphere
  - dilution in geosphere, biosphere

BOSS post-closure safety

Human intrusion releases

- long-term safety rests on low consequence of a “direct hit” from exploratory drilling
- probability of a “direct hit” is also very low but ICRP81 suggests that this cannot be quantified

Corrosion background 1

- Corrosion is an electrochemical process
- Basically two types of reaction:
  - anodic = metal dissolution = electron producing

$$M \rightarrow M^+ + e^-$$

  - cathodic = various reactions = electron consuming

$$O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$$

$$2H^+ + 2e^- \Rightarrow H_2 \text{ etc}$$

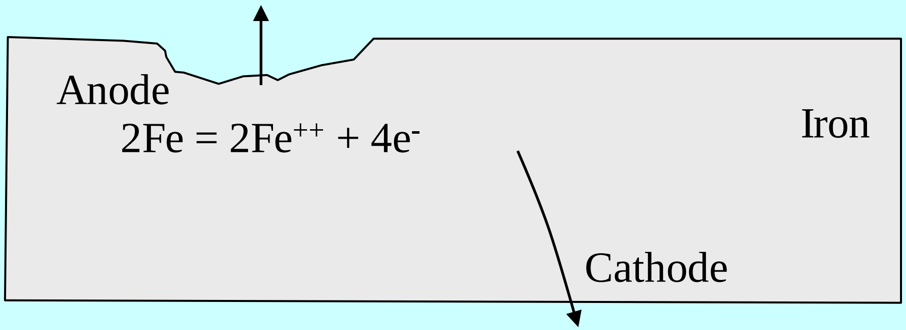
Corrosion background 2

- because electrons are mobile in the material that is corroding (and provided there is a continuous film of water)
  - –the anodic and cathodic reactions can occur in different places (but the electron flow must balance)
  - –moreover, the corrosion product can be formed at yet a third place

Corrosion background 3

$$2Fe(OH)_2 + O_2 = 2FeO.OH$$

$$2Fe^{++} + 4OH^- = 2Fe(OH)_2$$

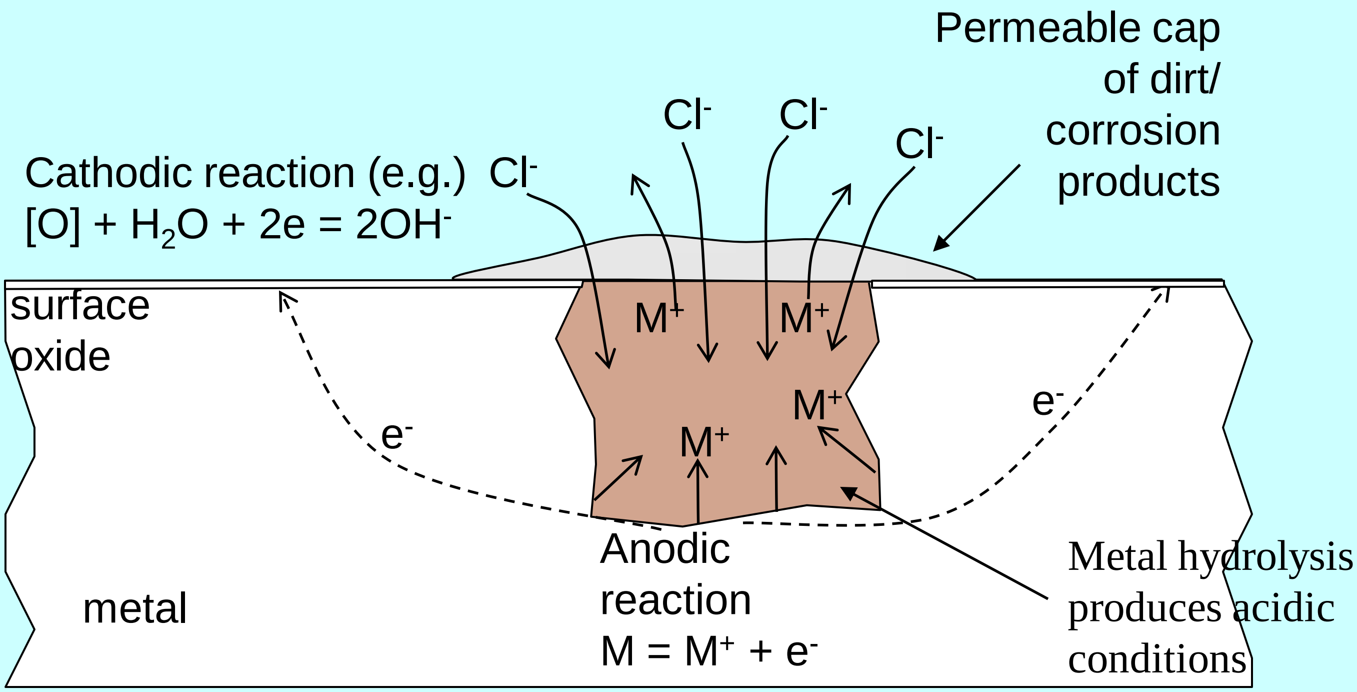


$$O_2 + 2H_2O + 4e^- = 4OH^-$$

corrosion always proceeds non-uniformly

this non-uniformity becomes more pronounced when the metal is generally resistant to corrosion - localised corrosion

Localised Corrosion - pitting

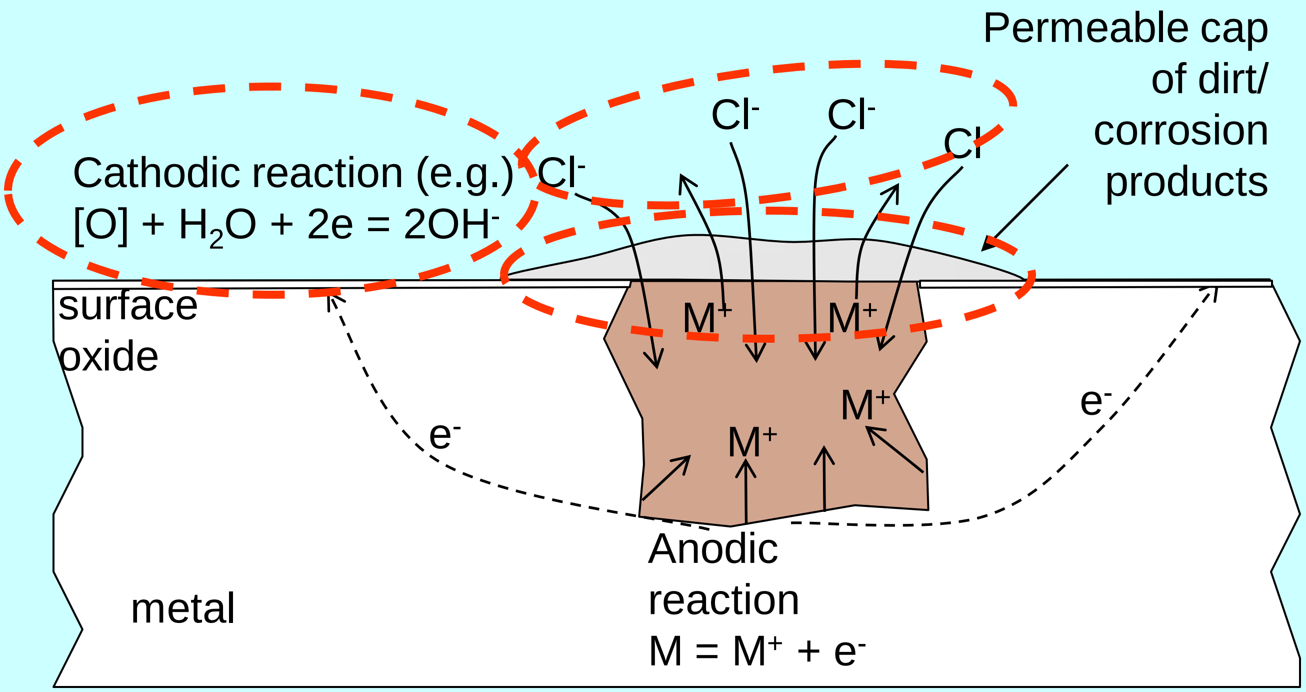


up to 10 microns/yr in seawater
up to 1 mm/yr under accelerated conditions

Forms of localised corrosion

- pitting corrosion
  - corrosion products/ dirt
- crevice corrosion
  - pre-existing crevice
- microbially induced corrosion (MIC)
  - microbial membrane
- stress corrosion cracking (SCC)
  - normally develops from a pit or crevice

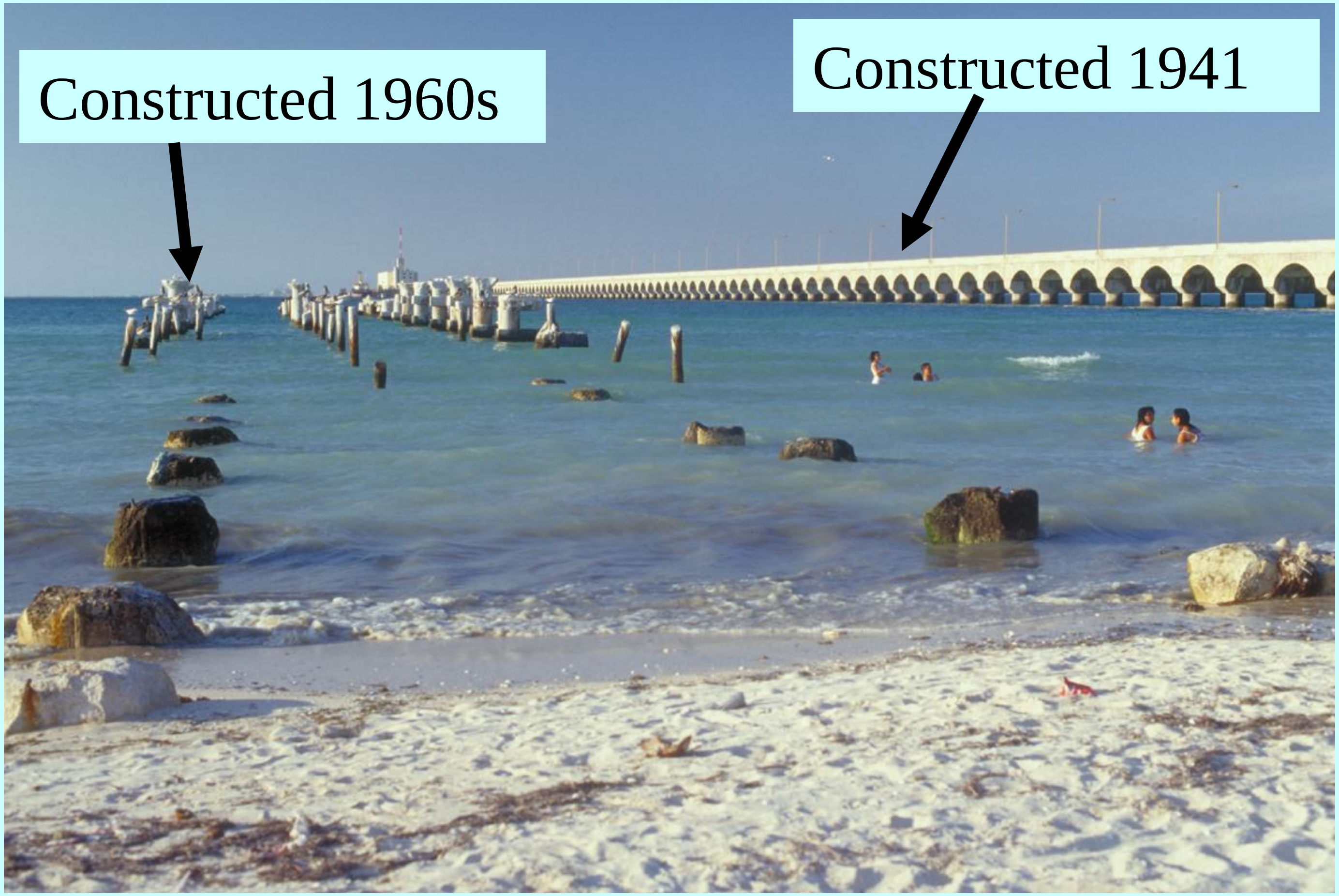
Avoiding localised Corrosion



Avoidance of localized corrosion

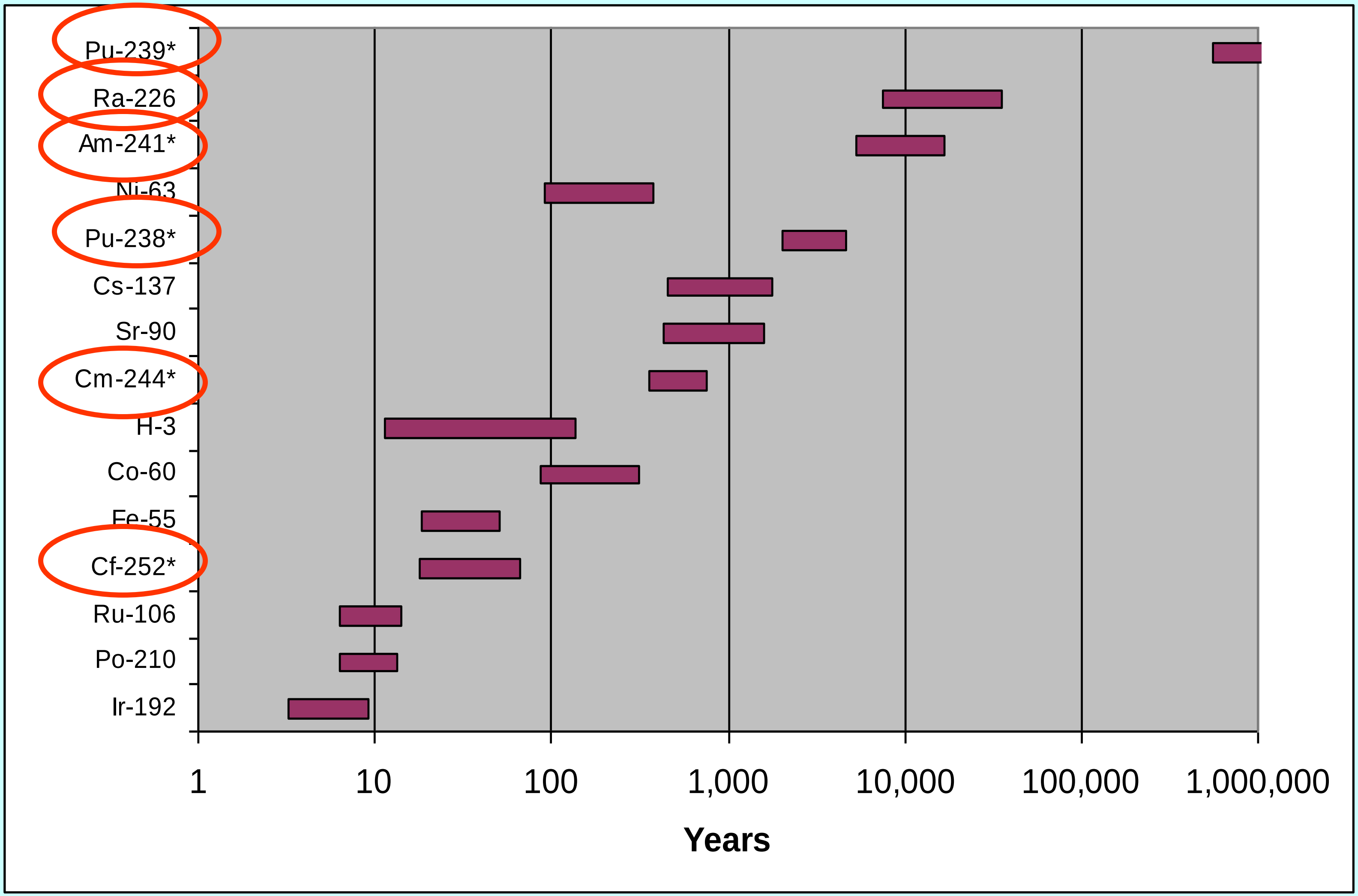
- Anaerobic conditions
  - rate of uniform corrosion too low to sustain localized corrosion (radiolysis?)
- Tolerable chloride in groundwater
  - up to 1000 ppm at neutral pH
  - up to 10,000 ppm at high pH
- Desirable concrete properties
  - high pH buffering
  - permeability not so important

Piers at Progresso, Mexico



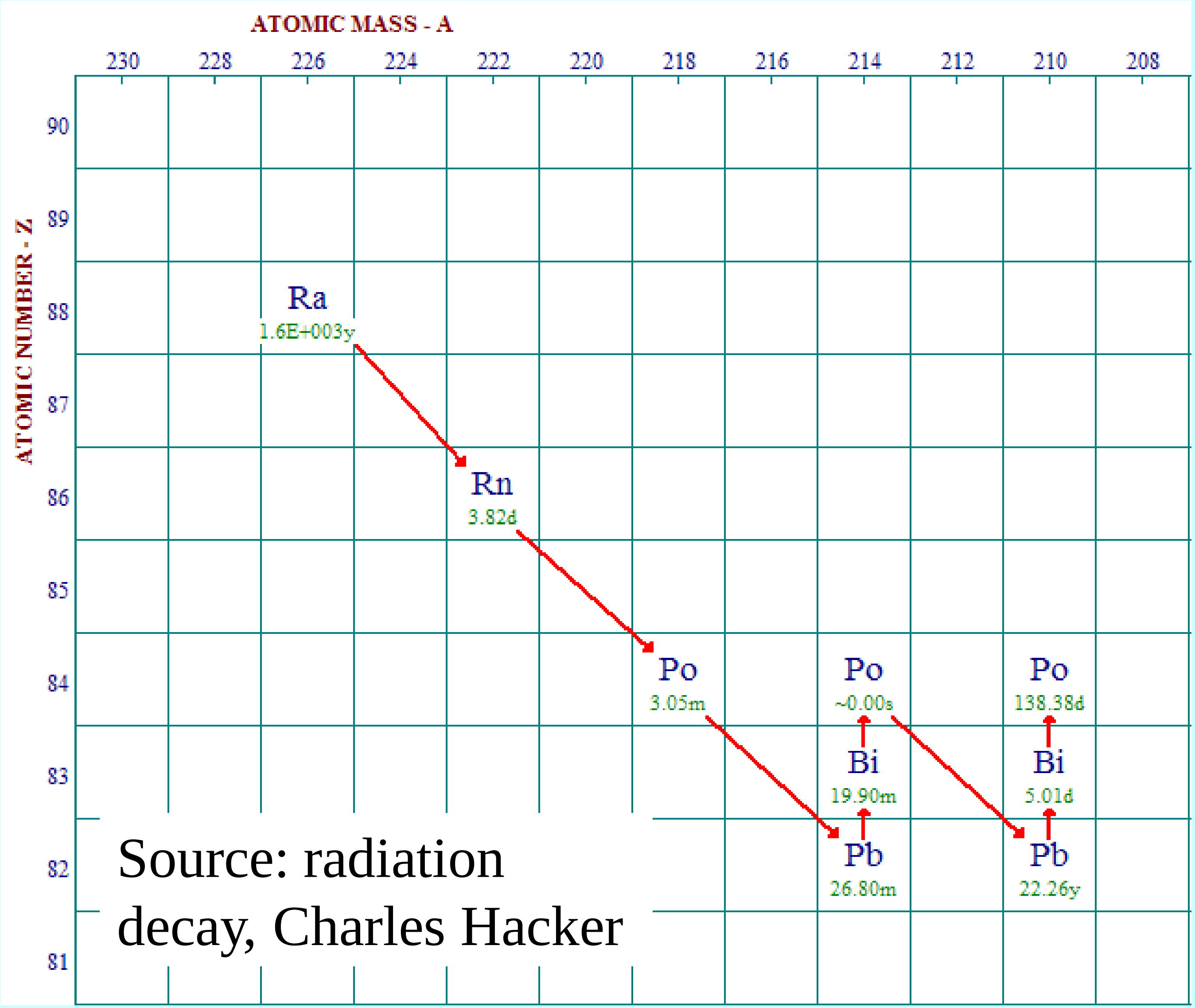
Stainless steel corrosion

- If localized corrosion can be avoided
- uniform corrosion only - 0.01 micron/a
- 9 mm thickness gives lifetime approaching 1 Ma (corrosion from one side only)
- compare with half lives of radionuclides of interest


Pu-239*
Ra-226
Am-241*
Ni-63
Pu-238*
Cs-137
Sr-90
Cm-244*
H-3
Co-60
Fe-55
Cf-252*
Ru-106
Po-210
Ir-192
1
10
100
1,000
10,000
100,000
1,000,000
Years

METALS NON METALS

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									
				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr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ATOMIC NUMBER - Z
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Po
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Po
138.38d
Bi
19.90m
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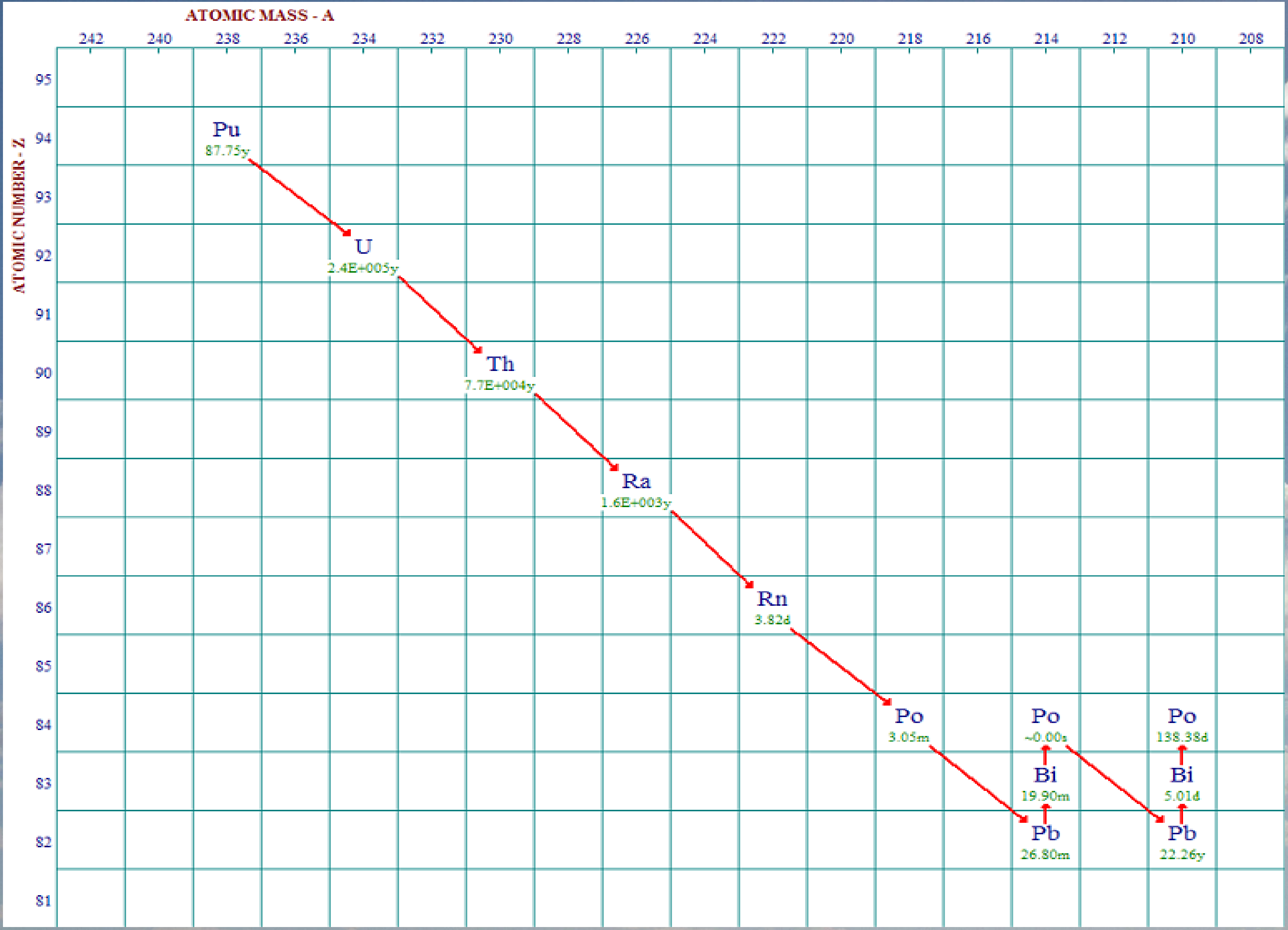
Pb
26.80m
Pb
22.26y
Source: radiation decay, Charles Hacker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ATOMIC NUMBER - Z
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Pu
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Th
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Ra
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Rn
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Po
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Pb
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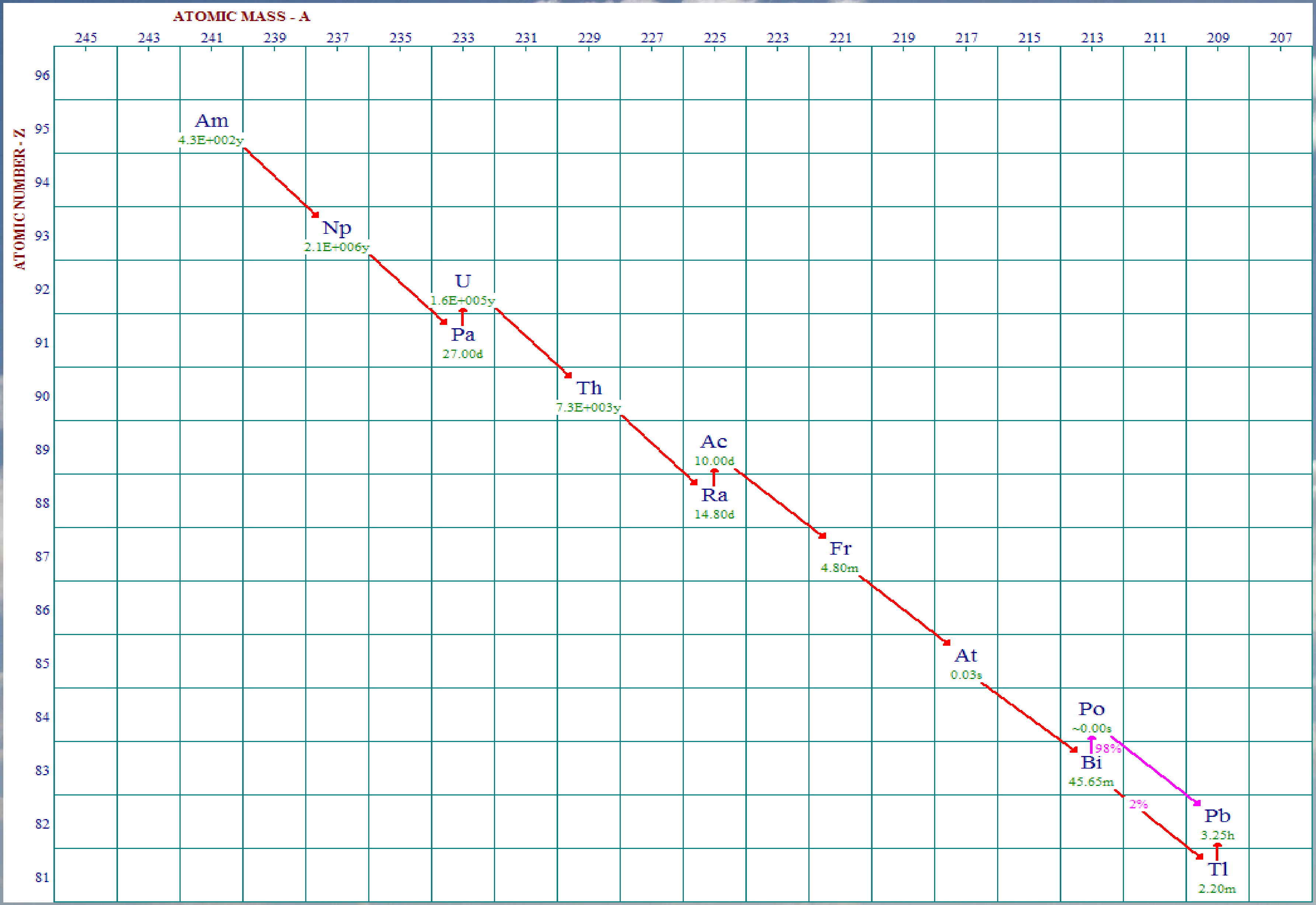
ATOMIC MASS - A
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ATOMIC NUMBER - Z
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82
81
Am
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Np
2.1E+006y
U
1.6E+005y
Pa
27.00d
Th
7.3E+003y
Ac
10.00d
Ra
14.80d
Fr
4.80m
At
0.03s
Po
~0.00s
98%
Bi
45.65m
2%
Pb
3.25h
Tl
2.20m

SRS radionuclides

	Half-life	10*h/l	cf 1Ma
• Ra-226	1600 a	16,000 a	ok
– all short-lived progeny			ok
• Pu-238	88 a	880 a	ok
– U-234	0.24 Ma	2.4 Ma	not ok
– Th-230	80,000	770,000	not ok
• Am-241	432 a	4,320	ok
– Np-237	2.1 Ma	21 Ma	not ok
– U-233	160,000 a	1.2 Ma	not ok
– Th-229	7,700 a	77,000 a	not ok

Dose impact

Provided

• localised corrosion can be avoided and

• half life of parent radionuclide and all progeny (if any) are less than a few thousand years

All radionuclides decay in situ and dose impact is zero

For longer-lived radionuclides, must rely on chemical containment

Why is borehole disposal of SRS safe?

- no very long-lived mobile radionuclides in the inventory
- high longevity of stainless steel container & capsule (if localized corrosion can be avoided)
- very long-lived radionuclides are immobile (low solubility, high sorption)