Unresolved Issues for Disposal of Radium-bearing Wastes at Hakes Landfill

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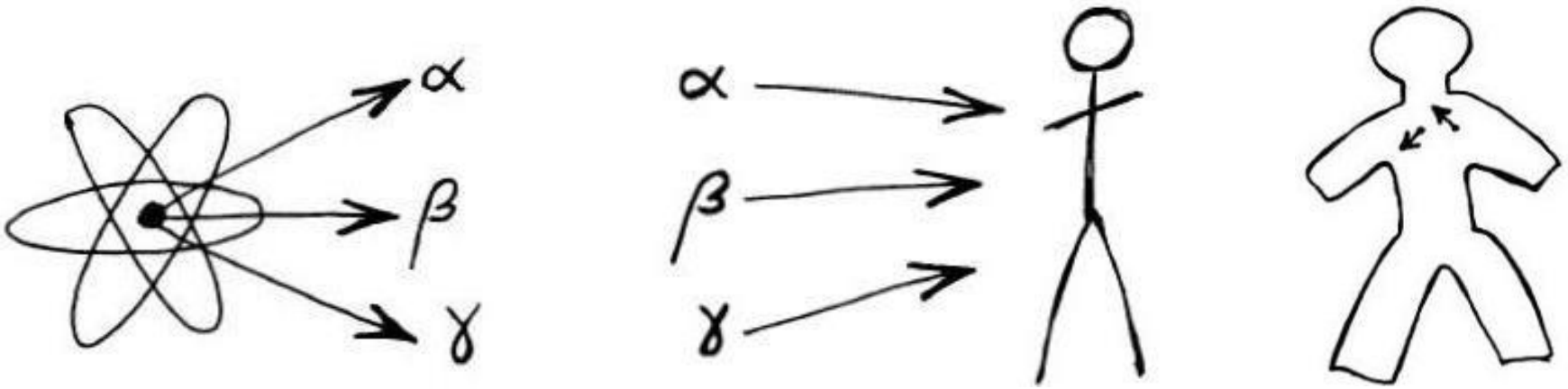
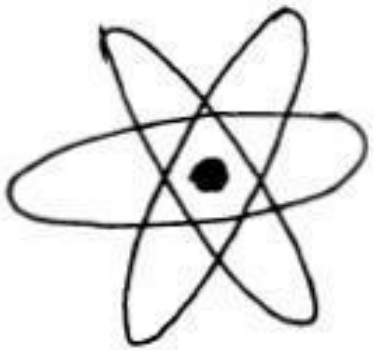
February 10, 2018



Overview of Radioactivity



Some atoms are ***stable:*** for example, **Carbon-12**

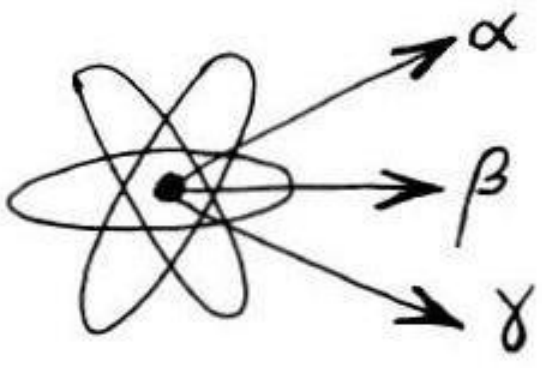
Some atoms are ***unstable*** (**radioactive**):

- Natural: for example, **Carbon-14, Potassium-40, Uranium-238, Radium-226, Radon-222**
- Manmade: for example, **Cesium-137, Plutonium-239**

Radiological Terminology

- **Radioactivity:** the process by which an unstable atom emits radiation and becomes a different atom that is generally more stable
- **Radiation:** energy in the form of waves or particles (*such as alpha or beta particles, or gamma rays*) given off by an unstable atom
- **Radioactive Material:** any substance or material that contains unstable atoms which give off radiation
- **Radioactive Contamination:** radioactive material in an unwanted or undesignated place
- **Decay:** process of radioactive atoms releasing radiation over a period of time and becoming stable (also called disintegration)
- **Half Life:** the time it takes for a group of atoms to decay to half of their original activity

RADIOACTIVE **EMISSION** or **ACTIVITY:**



Alpha particle

Beta particle

Gamma ray

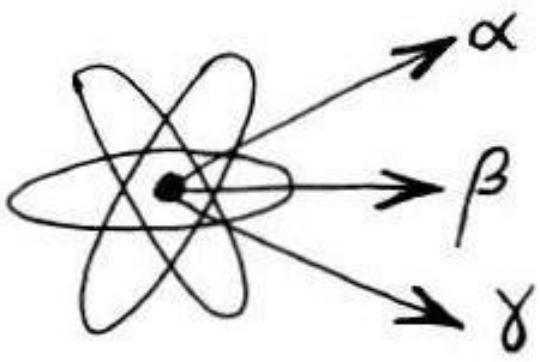
37 billion disintegrations per second = 1 Curie

(in other words, 37 billion unstable atoms per second are decaying and emitting particles/rays)

1/1,000,000,000,000 Curie = 1 picocurie (1 pCi)

1 disintegration every 27 seconds = 1 pCi

RADIOACTIVE **EMISSION** or **ACTIVITY:**



Alpha particle

Beta particle

Gamma ray

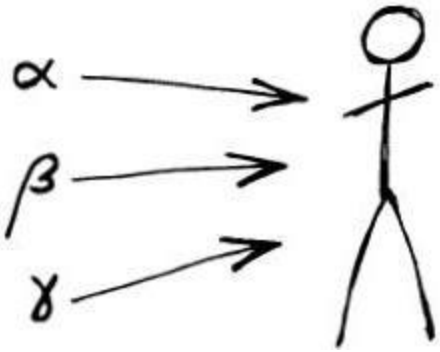
pCi

RADIOACTIVE **EXPOSURE** or **DOSE:**

Alpha particle

Beta particle

Gamma ray



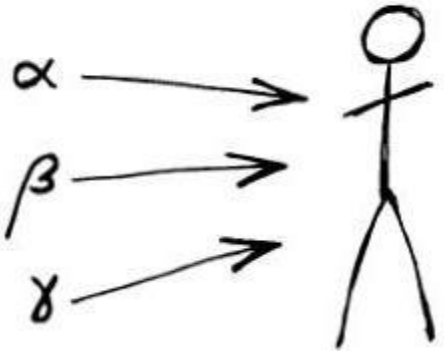
mrem

RADIOACTIVE **EXPOSURE** or **DOSE:**

Alpha particle

Beta particle

Gamma ray



1 rem = a measure of exposure or dose

1/1000 of 1 rem = 1 millirem (1 mrem)

Radioactive exposure or dose (mrem) can't be correlated with radioactive emission or activity (pCi) without knowing the exposure pathway or pathways. (*How are humans being exposed? Need details*.)

Penetrating power in living tissue:

ALPHA particle: Less than 1 millimeter, so usually can't penetrate human skin or a piece of paper -- but can be very damaging to living tissue if not protected by a barrier such as skin or paper

BETA particle: Can penetrate several millimeters in living tissue

GAMMA ray: Very penetrating (but depends on the energy of the gamma ray)

INTERNAL EXPOSURE if radioactive material is ingested or inhaled

With inhalation or ingestion, there's no protective barrier such as skin.

For example:

- Potassium-40
- Radium
- Radon (**GAS**) and its progeny or "daughters"

If ingested or inhaled, radioactive material can be in direct contact with intestinal lining, lung tissue, and other internal organs

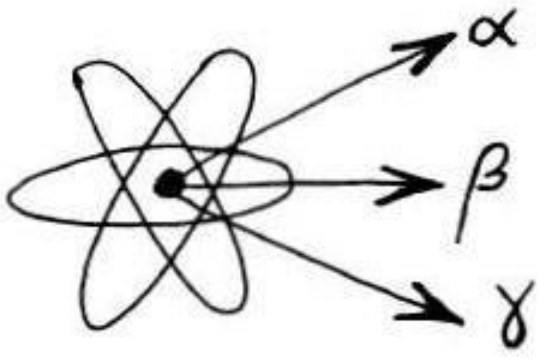
Are there pathways for ingestion or inhalation to occur? If so, the pathways need to be identified by measurement and/or modeling.

Exposure pathways?

Exposure pathways from Hakes landfill to humans have not been clearly identified or adequately investigated – but high levels of radon within the landfill and its leachate may cause *some* level of human exposure at downwind locations

Radium may also pose *some* level of long-term health risk for thousands of years if landfill integrity can't be guaranteed

Exposure pathways can/should be identified and quantified by testing and modeling – *preferably within an EIS process*



The Uranium-238 Decay Series (decay chain) and radionuclides such as radium, radon, lead, and bismuth in that decay chain

Uranium-238 (4.5 billion years)
↓
Thorium-234 (24 days)
↓
Protactinium-234m (1.2 minutes)
↓
Uranium-234 (240,000 years)
↓
Thorium-230 (77,000 years)
↓
Radium-226 (1,600 years)
↓
Radon-222 (3.8 days) (**GAS**)
↓
Polonium-218 (3.1 minutes)
↓
Lead-214 (27 minutes)
↓
Bismuth-214 (20 minutes)
↓
Polonium-214 (160 microseconds)
↓
Lead-210 (22 years)
↓
Bismuth-210 (5.0 days)
↓
Polonium-210 (140 days)
↓
Lead-206 (stable)

Uranium-238 decay series

(half-life in parentheses)

PARENT RADIONUCLIDE

PROGENY or DAUGHTER or DECAY PRODUCT

Uranium-238 decay series
(half-life in parentheses)

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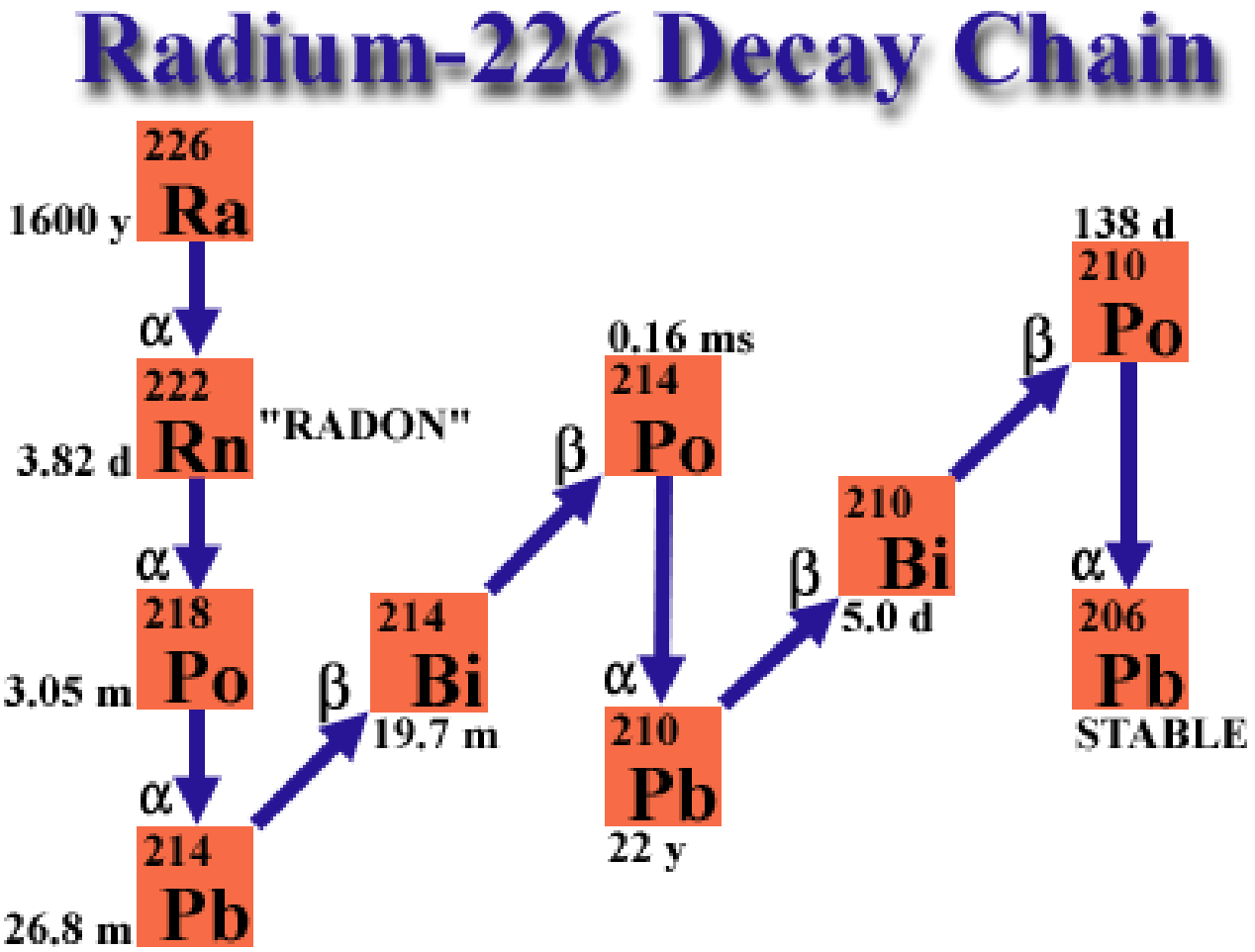


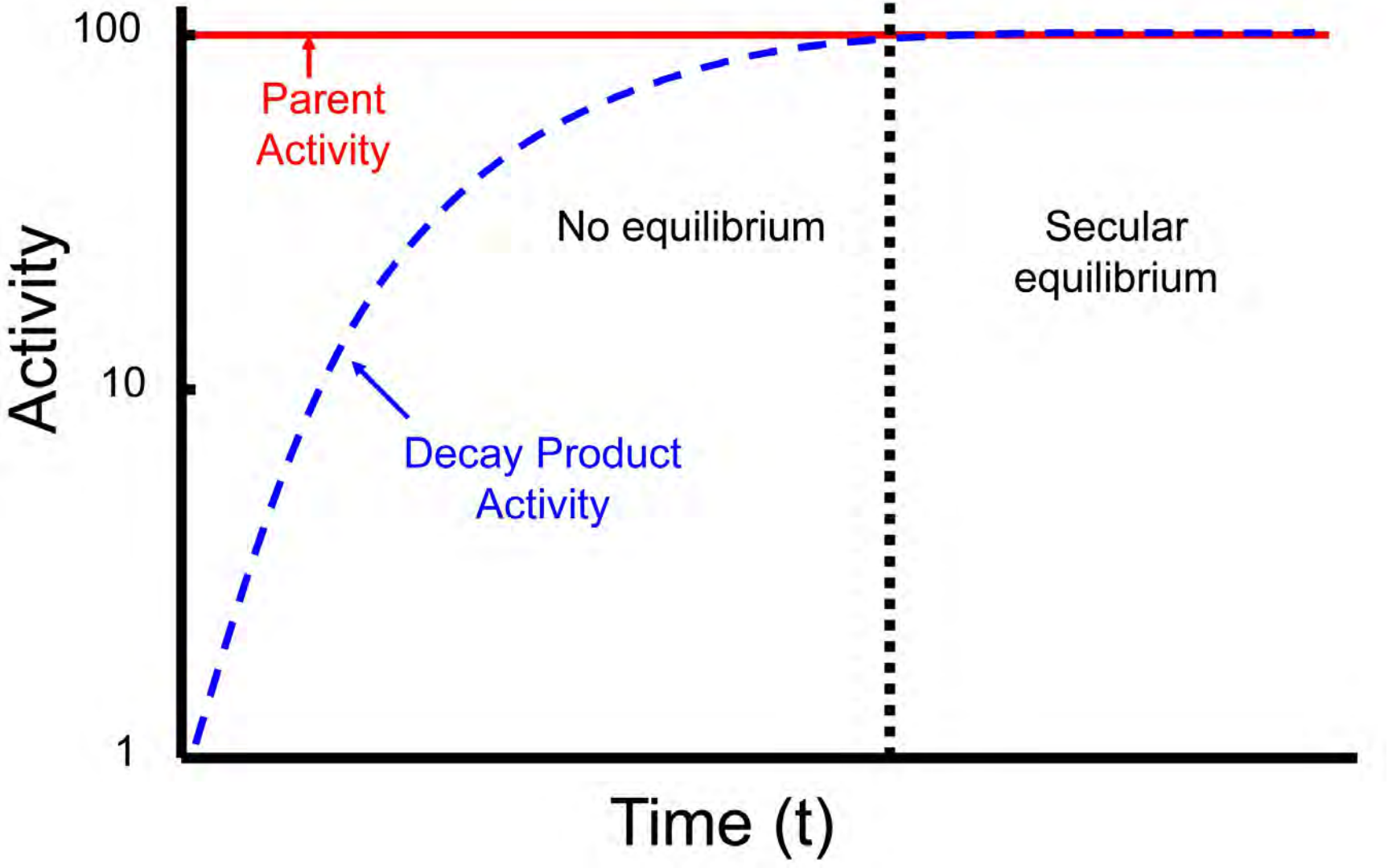
Secular Equilibrium

Secular equilibrium occurs if/when a relatively long-lived parent radionuclide is enclosed in a tight geologic matrix (such as relatively tight rock) *or in a sealed container*, thus keeping progeny trapped very close to the parent

In this circumstance, the activity of the progeny (in pCi) tends to be the same as the activity of the parent radionuclide. (The progeny stay "in sync" with the decay rate of the parent.)

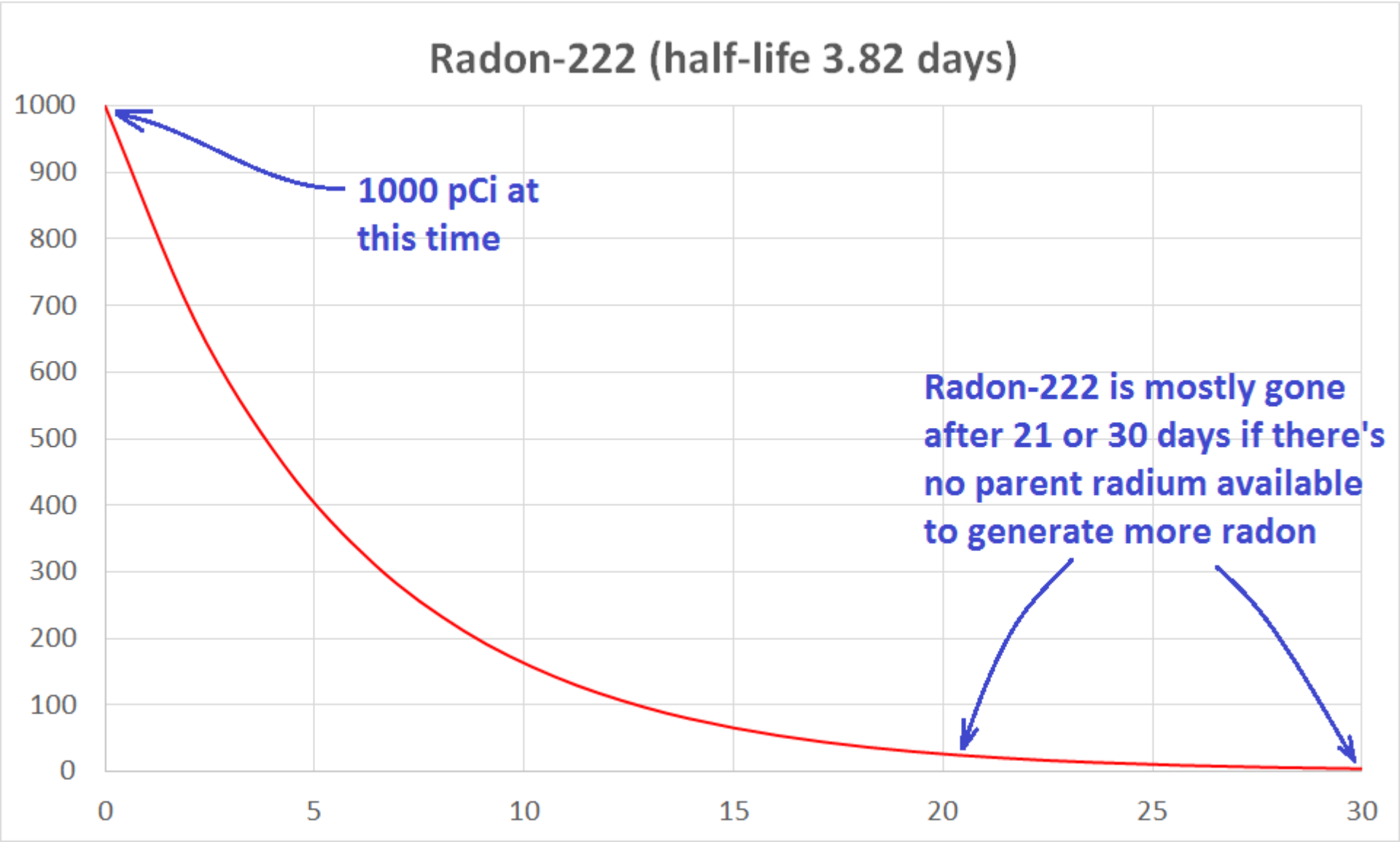
And even if the progeny are initially absent, they'll be generated and "catch up" if the parent is put into a sealed container.

Secular Equilibrium – "catching up"



Source: ORISE

Radioactive decay
without secular equilibrium with the parent



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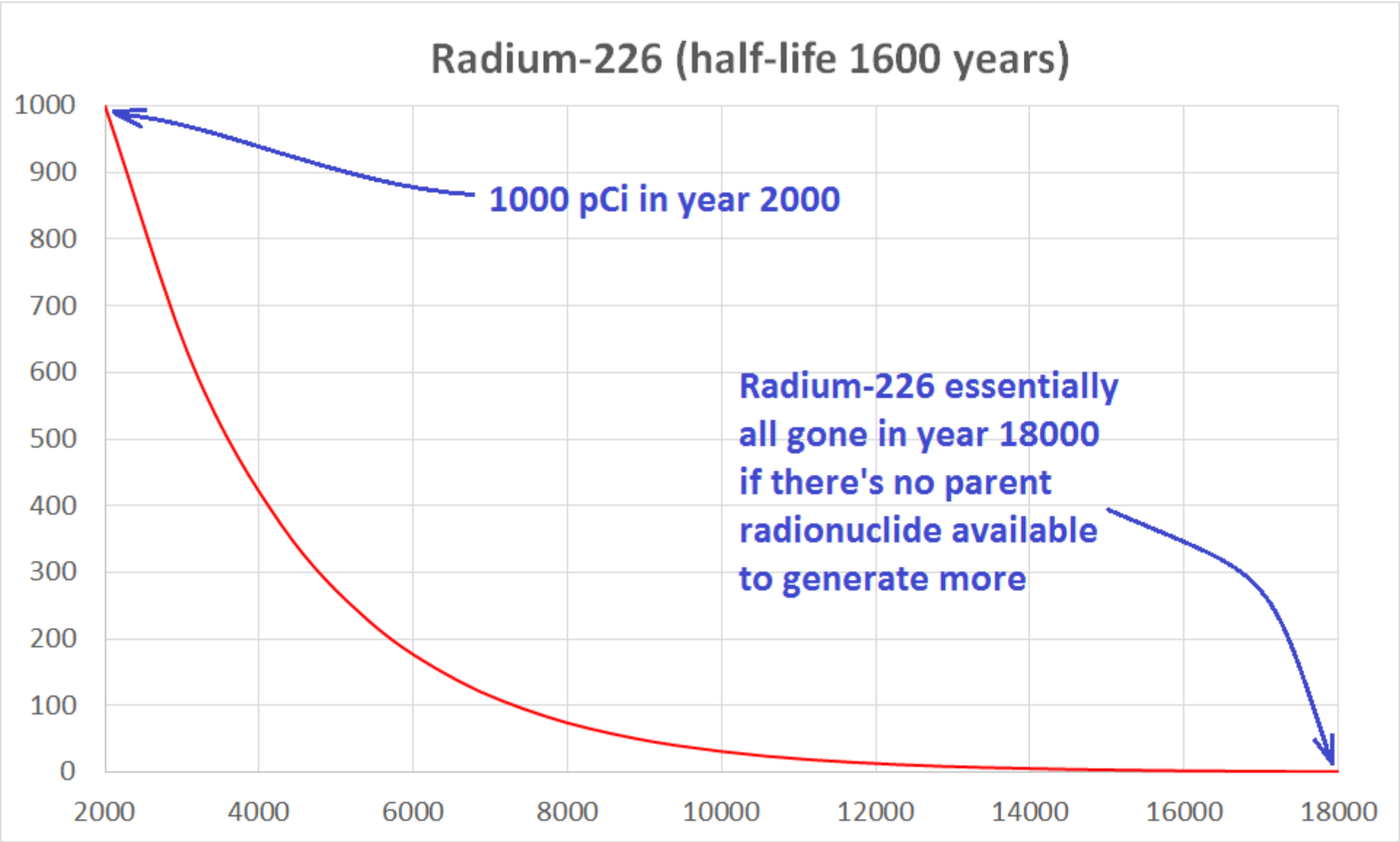

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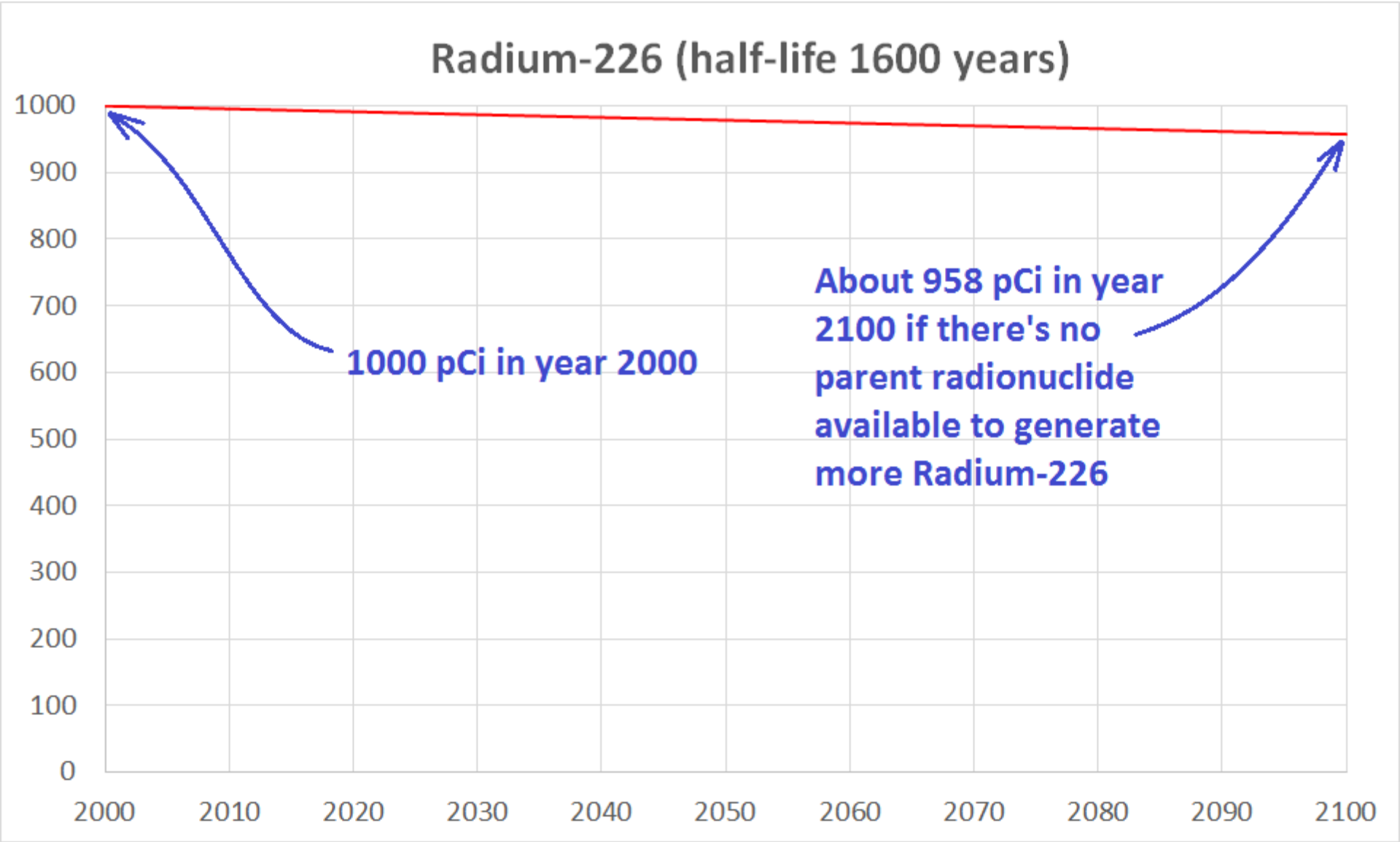

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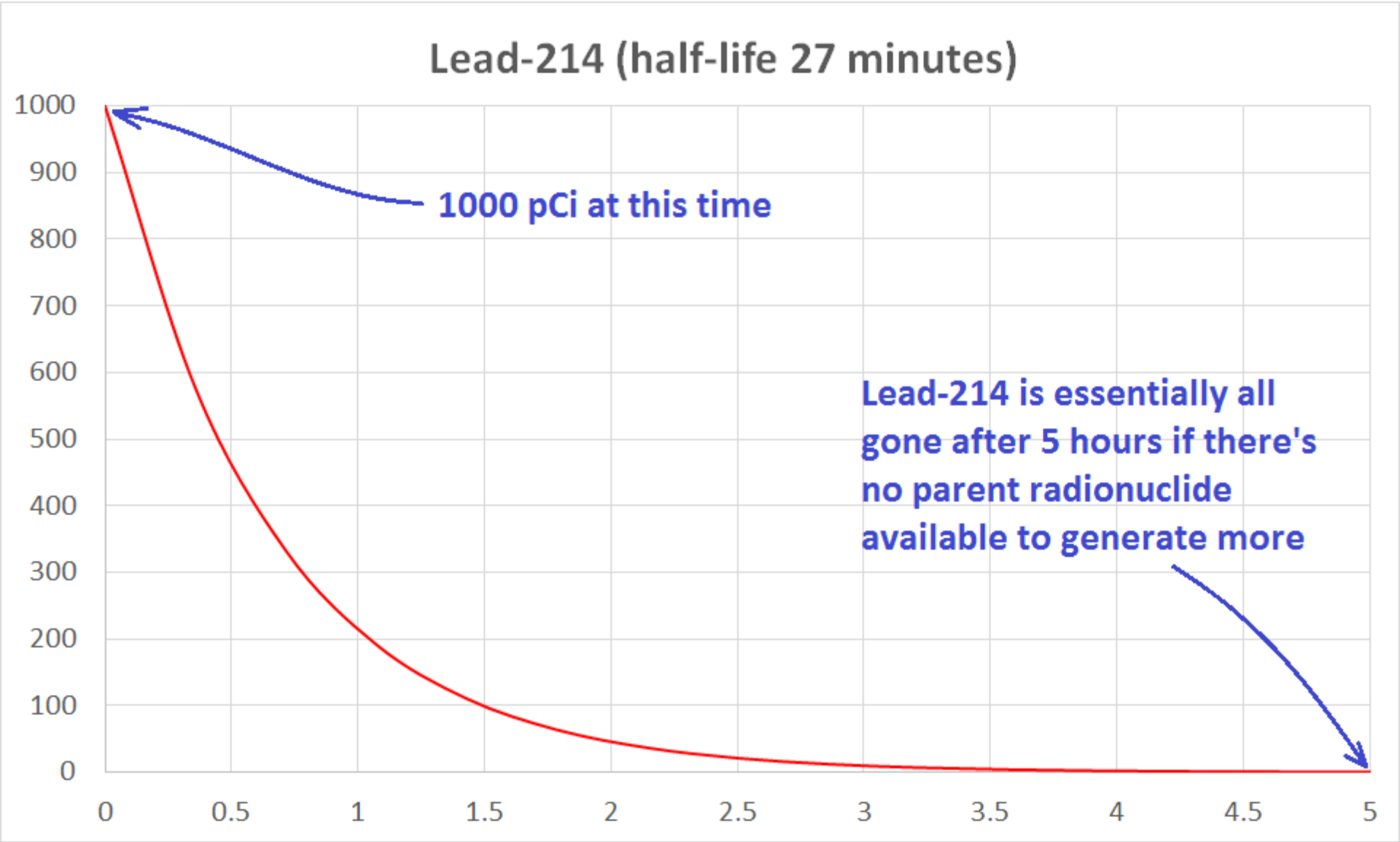

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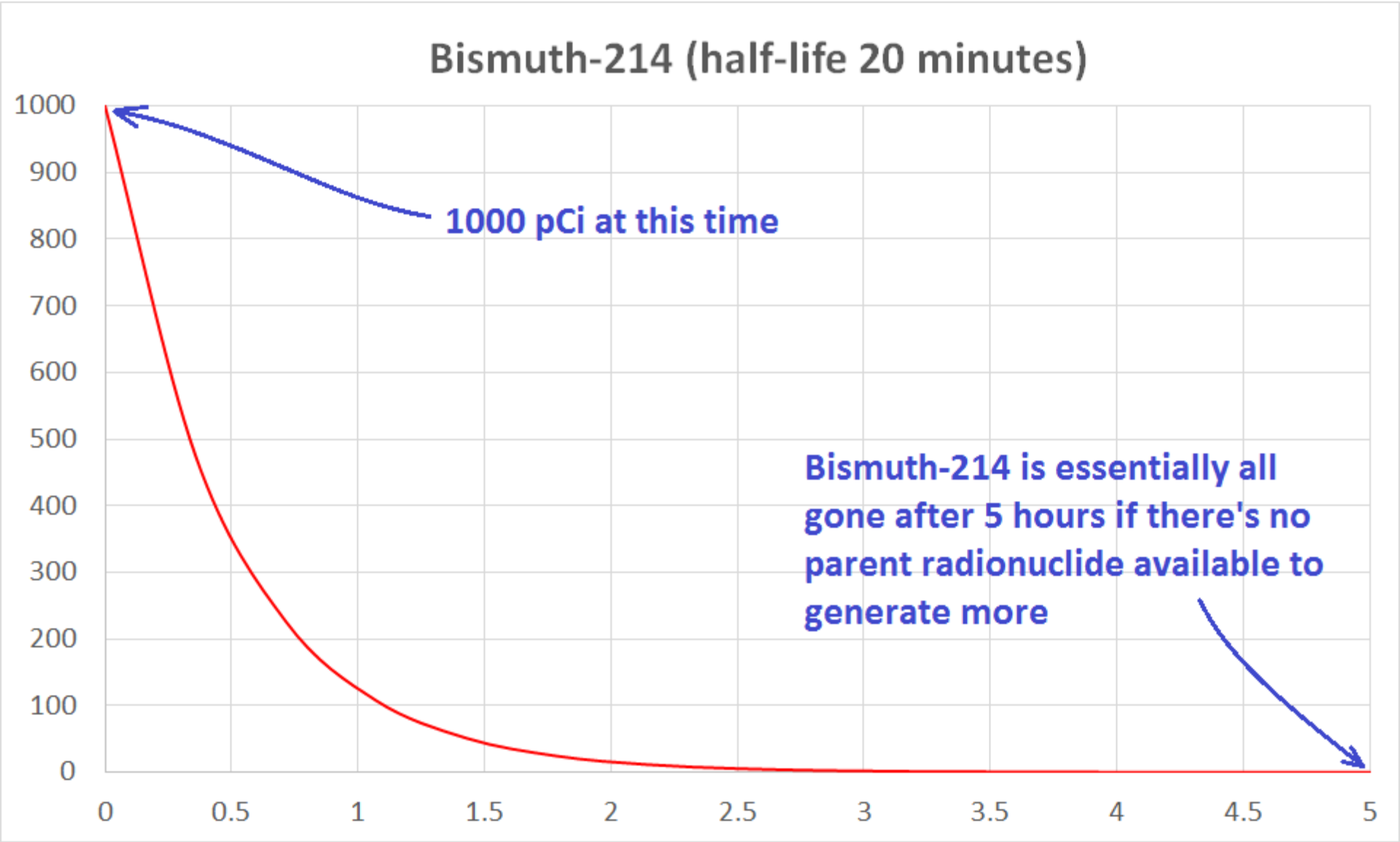
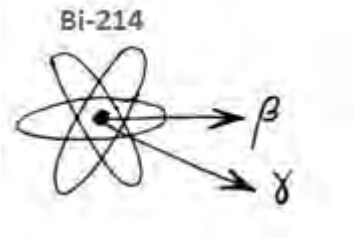


Lead-214 and Bismuth-214

Both of these radionuclides come from radon decay; both have such short half-lives that they'll be essentially gone within 5 hours if not constantly regenerated by radon decay. THUS:

- **Any Lead-214 or Bismuth-214 measured in a sample must be less than about 5 hours old…**
- **Indicating approx. secular equilibrium among Lead-214, Bismuth-214, and parent Radon-222**
- **Meaning that *Radon-222 must be present in a sample at approximately the same activity* (in pCi) *as Lead-214 and Bismuth-214* if the sample is more than about 5 hours old**



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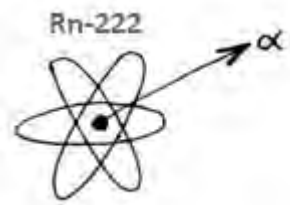
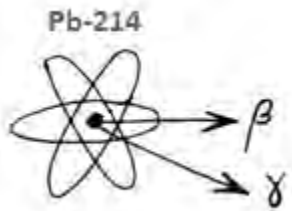


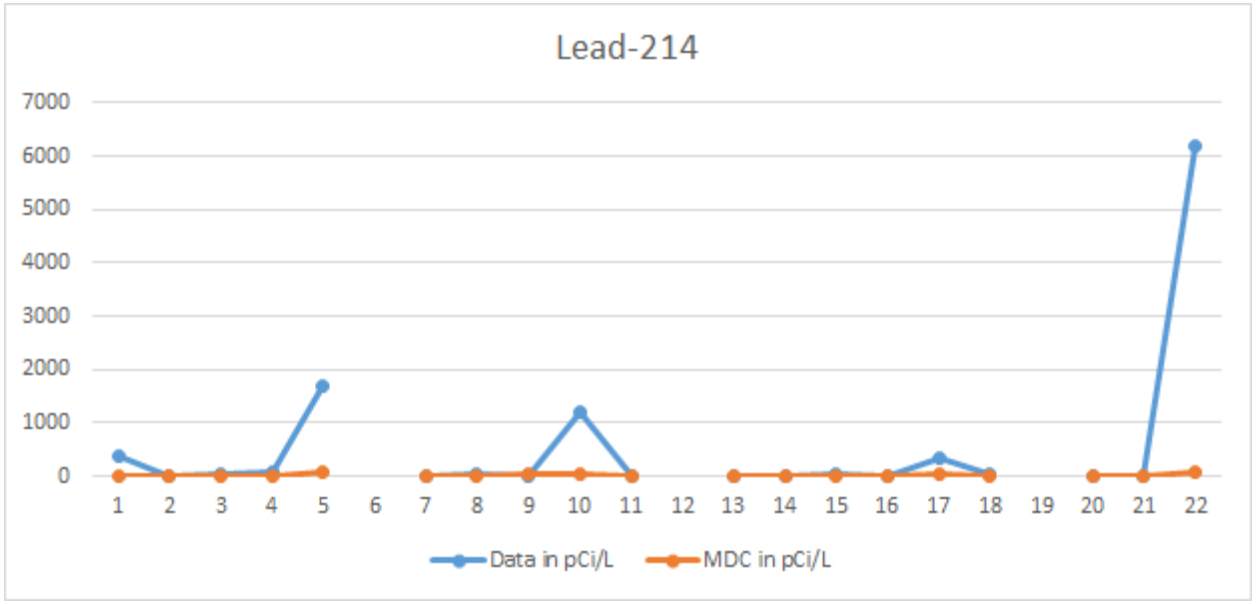


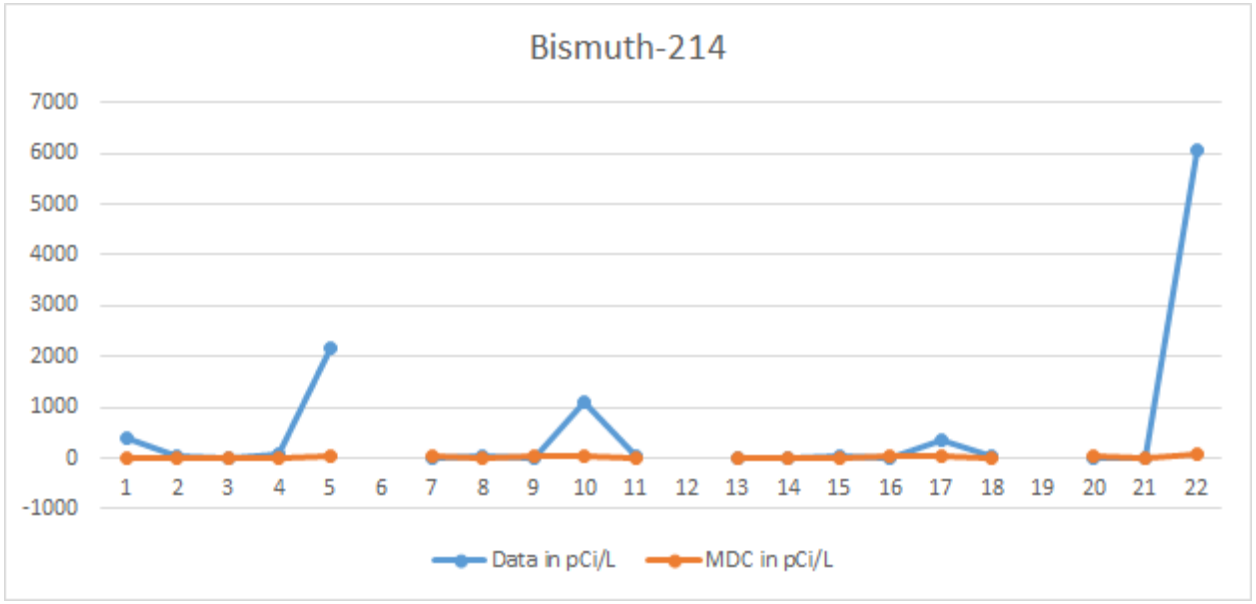
Applying these radiological principles to Hakes leachate test results

Lead-214, Bismuth-214, and Radon-222

Hakes leachate samples are generally not tested for Radon-222, but some of the test results show high levels of Lead-214 and Bismuth-214 (~6000 pCi/liter) in Hakes leachate samples at time of testing

Since these samples were held ~21 days before testing, the Lead-214 and Bismuth-214 results indicate that ~6000 pCi/liter Radon-222 was present in these Hakes leachate samples *at time of testing*

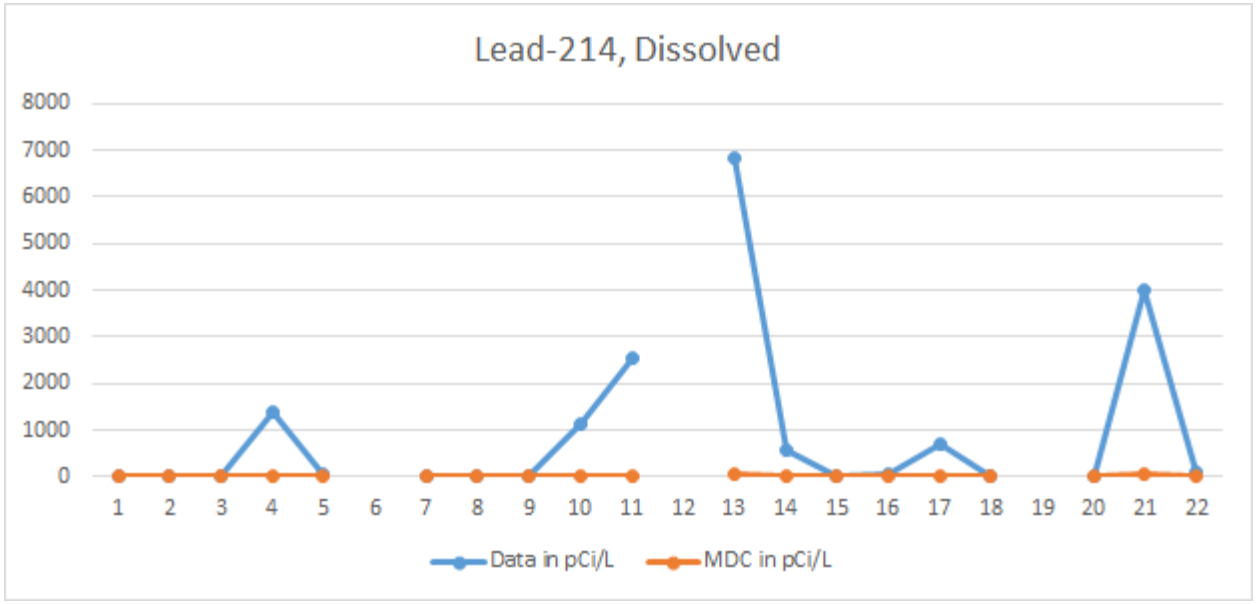


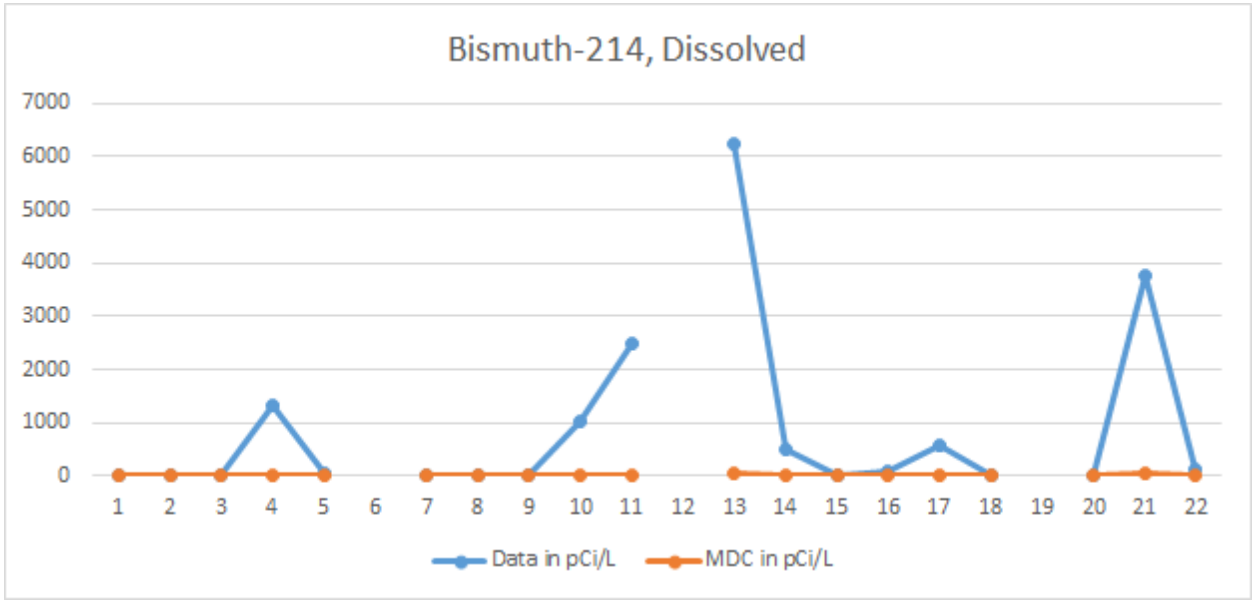


Hakes leachate test results (*in blue*) **and detection limits** (*orange*)

The horizontal axis on each graph is time, and the graphs show four different time trends:

- **1-5 are the 2015-17 time trend for Cell 3 Leachate**
- **7-11 are the 2015-17 time trend for Cell 4 Leachate**
- **13-18 are the 2014-17 time trend for Cell 5 Leachate**
- **20-22 are the 2016-17 time trend for Cell 8B Leachate**





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Lead-214, Bismuth-214, and Radon-222

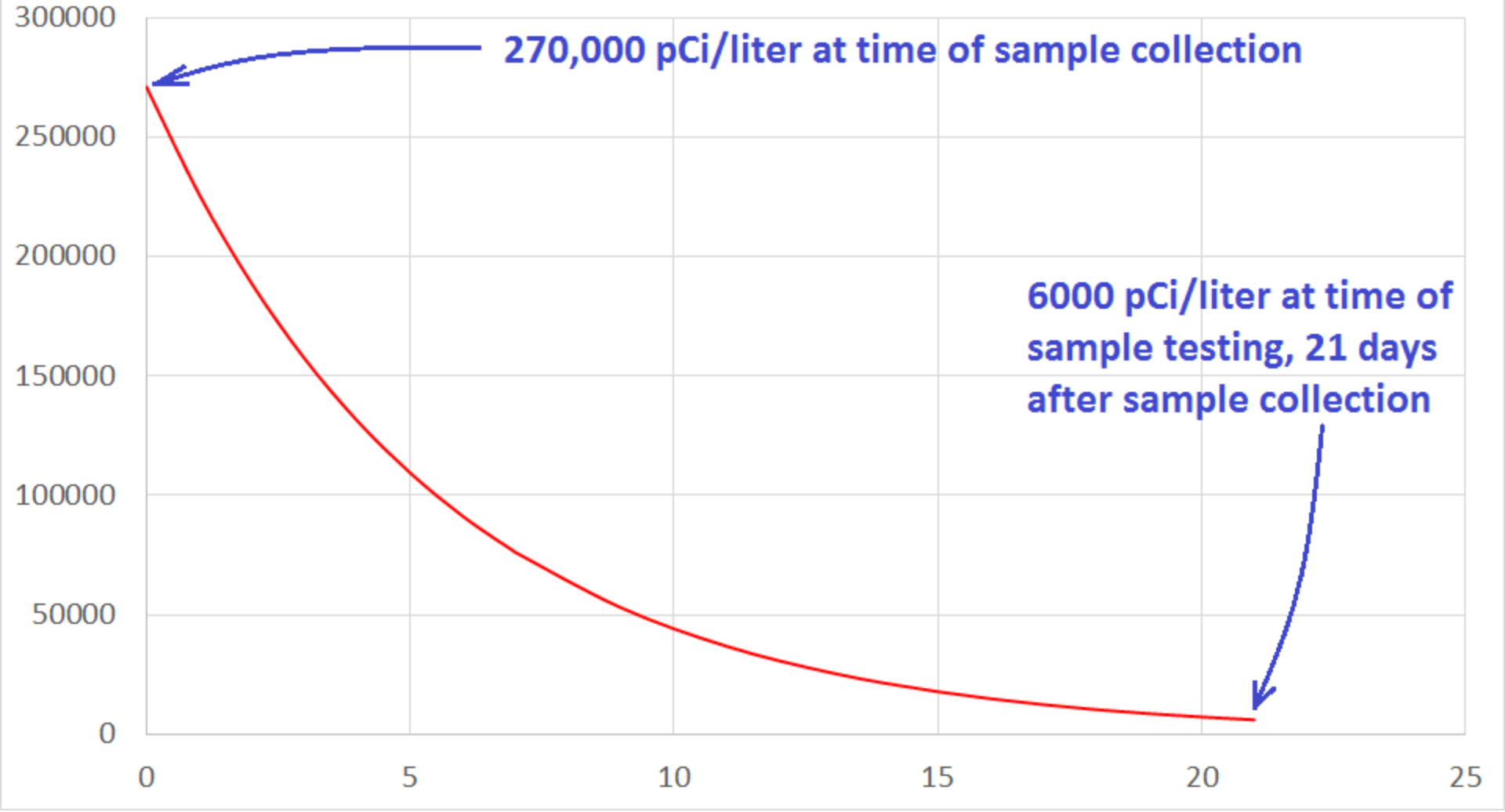
Hakes leachate tests show ~6000 pCi/liter Lead-214 and Bismuth-214, indicating ~6000 pCi/liter Radon-222 in leachate *at time of testing* – but not all samples show such high test results. WHY??

- **Radon level in leachate varies over time??**
- **Or radon level in leachate was relatively high when most/all samples were collected, but radon leaked out of many sample containers during the sample holding period of about 21 days?? (*This possibility is discussed in affidavit by our expert Dustin May*)**

Important points….

- **If radon leaked out of some sample containers, does this mean that Hakes leachate *usually* (not just occasionally) contains high levels of *radon*?? Can't know without additional testing**
- **Tests show low levels (less than 10 pCi/liter) of *Radium-226* in Hakes leachate:**
  - **This *doesn't* show or mean that radium levels in landfill are low**
  - **This *does* show that the radium in leachate can't generate much radon (<10 pCi/liter)**
- ***Radon* activity in some samples was ~6000 pCi/liter *at time of testing* – *but much higher in leachate from which samples were collected***

21-day decay curve for Radon-222 (half-life 3.82 days) in Hakes leachate without secular equilibrium with parent radium



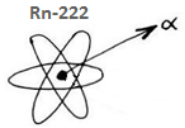
Important points….

- **Radon is a radioactive gas which, like other gases, can mix with air and can also dissolve in water and water-based mixtures such as leachate**
- **Radon activity in Hakes leachate from which samples were collected was (sometimes) ~270,000 pCi/liter**
- **Radon's equilibrium concentration (or activity) in *air* is related to its concentration (or activity) in *water* through known principles of physical chemistry involving *partition coefficient* and/or *Henry's Law.* (Provides a good approximation for water-based mixtures such as leachate.)**

At equilibrium in a sealed container, at 20ºC

1.05 million pCi/L Radon-222

in air



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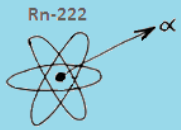


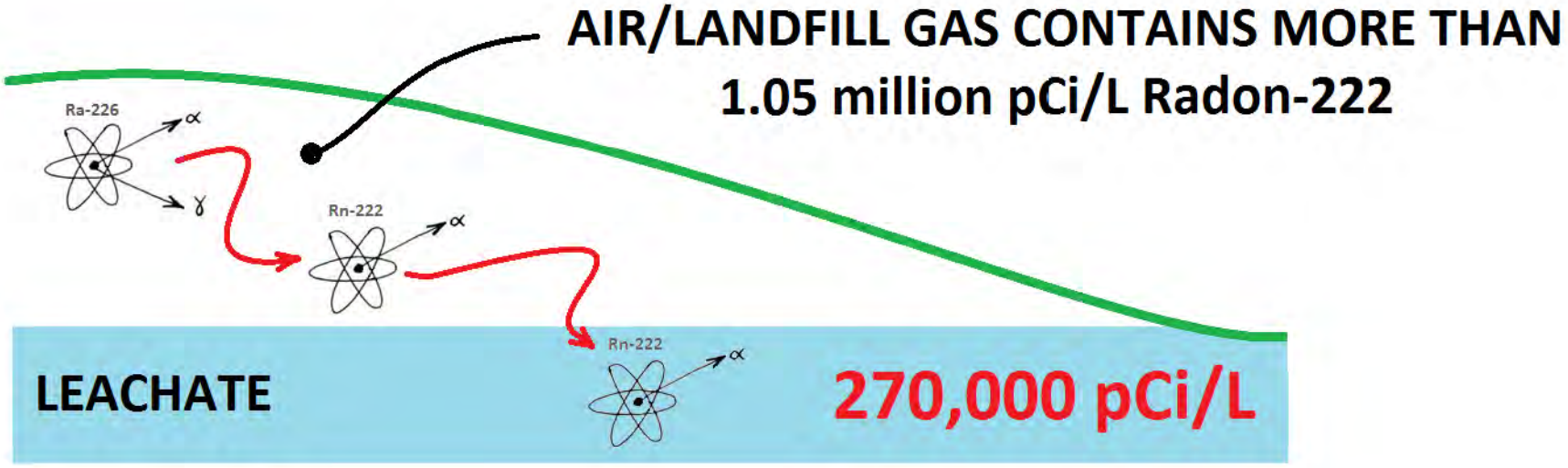
in water

Not at full equilibrium in an imperfectly sealed landfill, at ~20ºC

Likely: *Radium* remains dry

***Radon* reaches leachate by an air pathway**

>1.05 million pCi/L radon in air/landfill gas

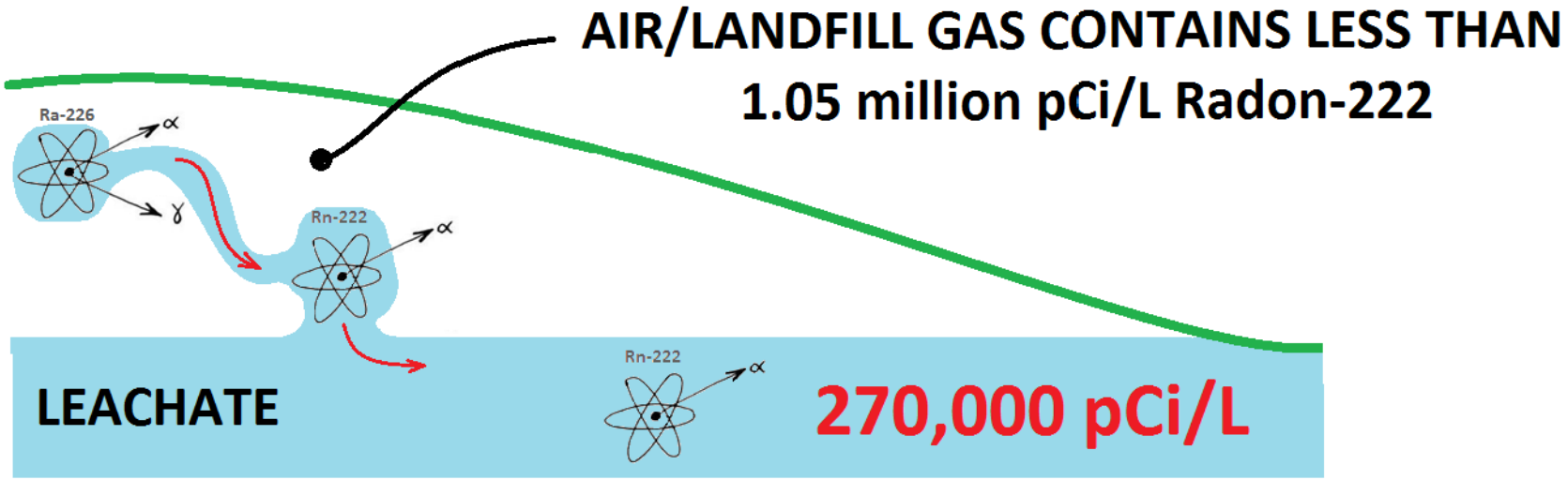


Not at full equilibrium in an imperfectly sealed landfill, at ~20ºC

Unlikely: *Radium* is immersed in water

***Radon* reaches leachate by water pathway**

<1.05 million pCi/L radon in air/landfill gas



Important points….

- **Radon activity in air/landfill gas within Hakes landfill may exceed ~1 million pCi/liter, either most of the time or part of the time. How much escapes through cap? *Testing needed.***
- **Testing and air dispersion modeling need to be conducted to determine radon activity at downwind locations and *ensure that landfill radon emissions don't cause exceedances of residential indoor-air guidance* (4 pCi/liter)**
- ***Radon in leachate* also needs attention/testing**
- **Radon comes from radium decay – *how much radium is in Hakes landfill?***

Three Widely Used Air Dispersion Models

AERMOD
ISCST3
CALPUFF

See also papers on radon dispersion modeling by Dong Xie (U. South China), K.J. Kearfott (U. Mich.) & others

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"Most of the Atmospheric Background Radiation is caused by radon and its decay products…. The atmospheric background varies greatly with wind direction and meteorological conditions. Radon also can be released from the ground in bursts and then form 'radon clouds' capable of traveling tens of kilometers."

Gamma Spectrometry: Gamma Radionuclides and X Ray Spectrometry, **Theremino System, Rev.2; http://www.theremino.com/wp-content/uploads/files/GammaSpec_ENG.pdf**

Matt Richmond photo, http://archive.alleghenyfront.org

Applying similar radiological principles to truck monitoring at Hakes landfill gate

Radiation monitoring at Hakes landfill gate is intended to limit incoming waste loads to no more than 25 pCi/gram Radium-226

- **As described in my affidavit, this type of monitoring cannot serve the intended purpose because highly variable and unknown levels of Lead-214 and Bismuth-214 interfere with Radium-226 monitoring**

- **Waste truckloads with up to 60-fold variations in their Radium-226 concentrations (activities) may exhibit the same or similar monitor readings**

Radiation monitoring at landfill gate cannot reliably limit incoming waste loads to no more than 25 pCi/gram Radium-226

- **Even if waste truckloads with Radium-226 concentrations (activities) that are only *eight times* the 25 pCi/gram limit were able to enter the Hakes gate without triggering the monitor, this would still allow disposal of unprotectively high levels (200 pCi/gram) of Radium-226**
- **Compare this to the radium background level in typical local soil (about 1 pCi/gram)**
- **ALSO: the radium limit in soil for home & other building sites (5 pCi/gram above background)**

Conclusions

Many unknowns – testing needed

Exposure pathways from Hakes landfill to humans have not been clearly identified or adequately investigated – but high levels of radon within the landfill and its leachate may cause some level of human exposure at downwind locations. *What exposure level?*

Radium may also pose some level of long-term health risk for thousands of years if landfill integrity can't be guaranteed. *What risk level?*

Current unknowns and exposure pathways can and should be identified & quantified by testing and modeling – *preferably within an EIS process*

Questions?