NORM 101

Properties of Uranium, Thorium, Radium, and Radon

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What is NORM?

- **NORM**: Naturally Occurring Radioactive Material – natural radioactivity (uranium, thorium, radium, radon…)

- Everything that comes from the ground is radioactive
  - Building materials
  - Food
  - Water
What is TENORM?

- Technologically Enhanced NORM - natural material whose radioactive concentrations have been enhanced by human activities **not including**:
  - Background or natural levels (NORM)
  - Byproduct material (man-made in reactors)
  - Source material (used to make reactor fuel)
  - Recovered uranium or uranium tailings
NORM / TENORM Nuclides

- Naturally Occurring Radioactive Material
  - Primordial radionuclides in their natural state
  - U-238, U-235, Th-232, K-40

- Technologically Enhanced NORM
  - Primordial radionuclides enhanced in concentration or location due to human actions
  - Ra-226, Ra-228, Po-210, Pb-210
Sources of NORM

- NORM: Naturally Occurring Radioactive Material – natural radionuclides (uranium, thorium, radium, radon…)
  - Fertilizer (phosphate ores – uranium)
  - Rare earth mine tailings (uranium, thorium)
  - Ceramic products (uranium in clay)
  - Welding rods (thorium oxides in coatings)
  - Coal (radium)
Sources of NORM (cont’d)

- Natural gas processing (radon decay products)
- Radon in homes (radon decay products)
- Radioactivity in consumer products
  - Uranium – red / orange glaze on ceramics (U-238)
  - Uranium – green / yellow coloring in glass (U-238)
  - Radioactivity in tobacco products (Pb-210, Po-210)
  - Radium dial instruments (Ra-226)
  - Thorium lantern mantles (Th-232)
  - Ceramic tiles (U-238, Ra-226)
  - Granite counter tops (U-238, Ra-226)
  - Light salt - KCl K-40 (0.0117 %)
TENORM in Natural Gas
Radon Decay Products may Collect in Pipes, Valves, Pumps
Should we be Concerned?

- Is that bad?
- What do we need to know to decide?
  - Radiation in our everyday world?
  - Possible exposures?
  - Regulations for safety?
  - How to do measurements?
  - What can we do for safety?
Properties of Uranium
## Uranium Decay Series

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half-Life</th>
<th>Radiations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}$</td>
<td>4.47 billion years</td>
<td>Alpha, x-rays</td>
</tr>
<tr>
<td>$^{234}\text{Th}$</td>
<td>24.1 days</td>
<td>Beta, gamma, x-rays</td>
</tr>
<tr>
<td>$^{234m}\text{Pa}$</td>
<td>1.17 minutes</td>
<td>Beta, gamma</td>
</tr>
<tr>
<td>$^{234}\text{U}$</td>
<td>2,480,000 years</td>
<td>Alpha, x-rays</td>
</tr>
<tr>
<td>$^{230}\text{Th}$</td>
<td>77,000 years</td>
<td>Alpha, x-rays</td>
</tr>
<tr>
<td>$^{226}\text{Ra}$</td>
<td>1,600 years</td>
<td>Alpha, x-rays</td>
</tr>
<tr>
<td>$^{222}\text{Rn}$</td>
<td>3.8 days</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{218}\text{Po}$</td>
<td>3.05 minutes</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{214}\text{Pb}$</td>
<td>26.8 minutes</td>
<td>Beta, gamma, x-rays</td>
</tr>
<tr>
<td>$^{214}\text{Bi}$</td>
<td>19.7 minutes</td>
<td>Beta, gamma, x-rays</td>
</tr>
<tr>
<td>$^{214}\text{Po}$</td>
<td>164 microseconds</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{210}\text{Pb}$</td>
<td>22.3 years</td>
<td>Beta, gamma, x-rays</td>
</tr>
<tr>
<td>$^{210}\text{Bi}$</td>
<td>5.01 days</td>
<td>Beta</td>
</tr>
<tr>
<td>$^{210}\text{Po}$</td>
<td>138 days</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{206}\text{P}$</td>
<td>Stable</td>
<td>None</td>
</tr>
</tbody>
</table>
Uranium

- Proton No. 92, Neutrons, 141 to 146
- U-238 = 99.24%, U-235 = 0.711%
  U-234 = 0.0058%
- Half-life 4.5 billion years
- U-235 is fissile (nucleus split by neutrons)
  - Fuel for reactors
  - Bombs
- Softer than steel, malleable, ductile
Uranium

- Discovered in 1789 – Martin Klaproth
- Found to emit energy by Becquerel -1896
- 70% more dense than lead
  - Good shield material
  - DU used for penetrators, in place of lead
- Enriched in U-235 (0.3%) for fuel (10-30 %)
- Huge tailings from radium separation
- Used as colorant in ceramics and glassware
  - By the Romans to make yellow glass
Uranium

- Avg. conc. 2 – 4 ppm, (0.7 to 15%)
  - 40 x that of silver
  - More plentiful than antimony, tin, cadmium, or mercury,
- Absorbed in plants (5 to 60 ppb)
- Uranium oxides, stable, low solubility
Uranium

- Exposure by inhaling dust or ingestion from water and food

- Ingested – most is excreted (95 - 99%)

- Absorbed – may go to bones (phosphate)

- Health risk – toxic damage to kidneys

- No human cancers from U
Properties of Thorium
## Thorium Decay Series

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half-Life</th>
<th>Radiations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{232}$Th</td>
<td>14.1 billion years</td>
<td>Alpha, x-rays</td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>5.75 years</td>
<td>Beta, gamma, x-rays</td>
</tr>
<tr>
<td>$^{228}$Ac</td>
<td>6.1 hours</td>
<td>Beta, gamma</td>
</tr>
<tr>
<td>$^{228}$Th</td>
<td>1.91 years</td>
<td>Alpha, gamma, x-rays</td>
</tr>
<tr>
<td>$^{224}$Ra</td>
<td>3.66 days</td>
<td>Alpha, gamma</td>
</tr>
<tr>
<td>$^{220}$Rn</td>
<td>55.6 seconds</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{216}$Po</td>
<td>0.15 seconds</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{212}$Pb</td>
<td>10.64 hours</td>
<td>Beta, gamma, x-rays</td>
</tr>
<tr>
<td>$^{212}$Bi</td>
<td>60.6 minutes</td>
<td>Alpha, beta, gamma</td>
</tr>
<tr>
<td>$^{212}$Po</td>
<td>0.305 microseconds</td>
<td>Alpha</td>
</tr>
<tr>
<td>$^{208}$Tl</td>
<td>3.07 minutes</td>
<td>Beta, gamma</td>
</tr>
<tr>
<td>$^{208}$Pb</td>
<td>Stable</td>
<td>None</td>
</tr>
</tbody>
</table>
Thorium

- Atomic No. 90, named for Thor, god of thunder
- 27 isotopes, Th-232, Th-230, Th-229, Th-228
- Thorium oxide, very high melting point, 3300°C.
- Used in lantern mantles, since 1885
- High quality camera lenses, welding electrodes
- Found in soil about 3 x Uranium, 6 - 12 ppm
  - Monazite – 12%, India has 25% of world reserves
- In food and water, excreted in few days
- Inhalation could cause lung damage
Properties of Radium
Radium – 226, 228

- Atomic No. 88, Ra-226 from U-238, alpha
- Ra-228 from Th-232, beta emitter
- Radium and ZnS are phosphorescent
- Found in soil everywhere,
- Decays to radon (greater risk than radium)
- In food and water, 80% excreted,
  - Accumulates in bones (like calcium)
Fig. 11. Cumulative bone sarcoma incidence in people exposed to $^{226}\text{Ra}$ as a function of cumulative dose to the skeleton as reported by Evans et al. (1972).
Properties of Radon
What is Radon?

- A naturally occurring, radioactive gas
  - Comes from uranium, radium in the soil
- Chemically inert
  - Heaviest noble gas
- Invisible and odorless
  - Cannot be detected by our five senses
- Accumulates in buildings
  - Amount can only be determined by testing
Uranium Decay Chain

Source of Radon

Dose to Lungs Due to
What is the Radon Problem?

- Radon gives 74% of avg. natural radiation dose
  - 229 mrem/yr (according to NCRP at 1.3 pCi / L)
  - 212 from radon decay products, 17 from thoron
  - 21,000 lung cancer deaths / yr in U.S. according to USEPA

- EPA calculated risks for lifetime exposure to 1.3 pCi/L (70% occupancy)
  - 20 in 1,000 for current smokers
  - 2 in 1,000 for non-smokers

- Extrapolated from studies of underground uranium miners
On The Other Hand

- Schneeburg Study (Belgium) shows decrease risk at low levels; no increase risk until > 6 – 10 pCi/L
On The Other Hand (cont’d)

  
  - Conclusion - no evidence for excess lung cancer risk below 800 Bq/m³ (approximately 6 pCi/L)

- Excess risk of lung cancer due to low concentrations of radon has been neither empirically detected nor theoretically demonstrated
Radon levels vary widely in the USA.
Based on EPA’s guidance, we would expect to see higher rate of lung cancers in the higher radon areas colored green, yellow, and red in the above map.

http://www2.lbl.gov/Science-Articles/Archive/radon-risk-website.html
Lung Cancer Mortality Rates in the USA (1970-2004)

Lung Cancer Rates vary widely across the USA

From: https://ratecalc.cancer.gov/ratecalc/

Dade Moeller, an NV5 Company
Higher radon counties (green, yellow, red) correspond to mostly lower rates of lung cancer (blue). Higher lung cancer counties (red) correspond mostly to lowest radon areas (blue).
A few Examples of TENORM

- Oil field pipe scale  
- Oil field / refinery sludge  
- Geothermal waste  
- Denver radium waste  
- Drinking water purification waste  
- Metals from certain ores  
- Paper making (Alum)
Oil Field Waste

- **NORM** radionuclides may be concentrated in the oil recovery process
  - Radium is more soluble in brine solutions than uranium or thorium
  - Carbonates and sulfates of calcium, barium, and strontium may precipitate as pipe scale (divalent cations)
  - Radium will also precipitate in pipe scale
  - Sludge in refineries will also contain radium
# Oil Field Waste: Radionuclide Content

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Average Sludge (pCi / g)</th>
<th>Average Scale (pCi / g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{210}$ Po</td>
<td>56</td>
<td>360</td>
</tr>
<tr>
<td>$^{210}$ Pb</td>
<td>56</td>
<td>360</td>
</tr>
<tr>
<td>$^{226}$ Ra</td>
<td>56</td>
<td>360</td>
</tr>
<tr>
<td>$^{228}$ Th</td>
<td>19</td>
<td>120</td>
</tr>
<tr>
<td>$^{228}$ Ra</td>
<td>19</td>
<td>120</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>206</strong></td>
<td><strong>1,320</strong></td>
</tr>
</tbody>
</table>

*EPA Data*
TENORM Pipe Scale
NORM Pipe Scale

- Found in pipe scale, 2 – 3 mR / hr in contact
- Deposits of radium with barium sulfate
Gas Pipeline “Pigging” Waste
Measurable radon in natural gas

- Results in Pb-210; 22 year half-life
- Po-210 5.3 MeV alpha
- Po is electrostatic
- Po attaches to rust
- Potential inhalation hazard
Oil Field Wastes

Production Water

Production Sludge
Environmental Issues

- **Water issues**
  - Large quantities \((15,000 \text{ m}^3)\) used as part of fracturing fluids; depletion of water resources
  - Waste water; flow back water (injection fluids), production water (saline water liberated along with O&G)

- **API estimates:** 10 barrels of water recovered per barrel of oil; 18 billion barrels of waste fluid produced per year
## PA TENORM Study Average Results (Bq/g or *Bq/L)

<table>
<thead>
<tr>
<th>Well Sites/Pads</th>
<th>$^{226}$Ra</th>
<th>$^{238}$U</th>
<th>$^{228}$Ra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Cuttings</td>
<td>0.1</td>
<td>0.06</td>
<td>N/A</td>
</tr>
<tr>
<td>Horizontal Cuttings</td>
<td>0.2</td>
<td>0.3</td>
<td>N/A</td>
</tr>
<tr>
<td>Fracking Fluid</td>
<td>*200</td>
<td>N/A</td>
<td>*20</td>
</tr>
<tr>
<td>Flowback Water</td>
<td>*300</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Produced Water</td>
<td>*200</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Drill Muds</td>
<td>*80</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Special Concerns

- Radiation exposures during operations
  - Emissions (air/water)
  - Radon
  - Contamination control
  - Lack of regulated disposal

- Public
  - Radon, transportation, waste management

- Legacy contamination after well site decommissioning
## Other NORM Wastes

<table>
<thead>
<tr>
<th>Material</th>
<th>Million Tons/yr</th>
<th>Ra – 226 pCi/g</th>
<th>µR/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphate</td>
<td>40</td>
<td>33</td>
<td>60</td>
</tr>
<tr>
<td>Coal Slag</td>
<td>43</td>
<td>3.7</td>
<td>7</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0.6</td>
<td>155</td>
<td>280</td>
</tr>
<tr>
<td>Mineral Proc.</td>
<td>1 billion T/y</td>
<td>35</td>
<td>60</td>
</tr>
<tr>
<td>Water Treat.</td>
<td>0.3</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.07</td>
<td>160</td>
<td>300</td>
</tr>
</tbody>
</table>
Waste Forms

- **Bulk solid waste** (soil, rubble, debris)
- **Industrial / mining waste**
- **Must be consistent with RCRA Permit**
- **Some treatment may be required, consistent with current procedures**
  - Drinking water treatment waste may require solidification
  - Treatment to encapsulate arsenic or other metals
U.S. Future?

- Given the global recognition of the problem, what are the future/current options in the U.S.

- Confluence of history, science, and common sense
  - State/CRCPD activities
  - Industry evaluations and self-regulation?
  - A harmonized approach?
Purpose: To prepare a Commentary that provides: Recommendations for a Uniform Approach for Hydraulic Fracturing NORM/TENORM Waste Disposal and lays the ground work for a more comprehensive Report…

Consistent with NCRP Mission: to formulate and widely disseminate radiation protection recommendations
SC 5-2 Membership

David Allard        PDEP
Martin Barrie       ORAU
Phil Egidi          U.S. EPA
Gary Forsee         Illinois Environmental Compliance
Raymond Johnson    Radiation Safety Counseling Inst.
Andrew Lombardo     PermaFix
Ruth McBurney       CRCPD
John Frazier        Consultant Co-Chair
W.E. Kennedy, Jr.   Dade Moeller Co-Chair
What’s Next?

- **Awareness training**
  - Ethical and legal responsibility to protect workers
  - OSHA and employee right-to-know regulations

- **Radiation surveys/sampling**
  - To confirm compliance and safety (PA lead)

- **Workplace/environmental monitoring?**

- **Changing regulatory/public opinion landscape**
  - Litigation avoidance!
NORM Summary

- Numerous natural radionuclides, at low concentrations
- Predominantly uranium, thorium, radium
- Found in all materials coming from the ground
- Pipe scale, sludges, wastes
- Concerns for worker safety and environmental protection
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