Understanding Radioactivity through the Exploration and Mining Cycle

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SRC Land Acknowledgement

SRC’s headquarters in Saskatoon is situated on Treaty 6 Territory and the Homeland of the Métis.

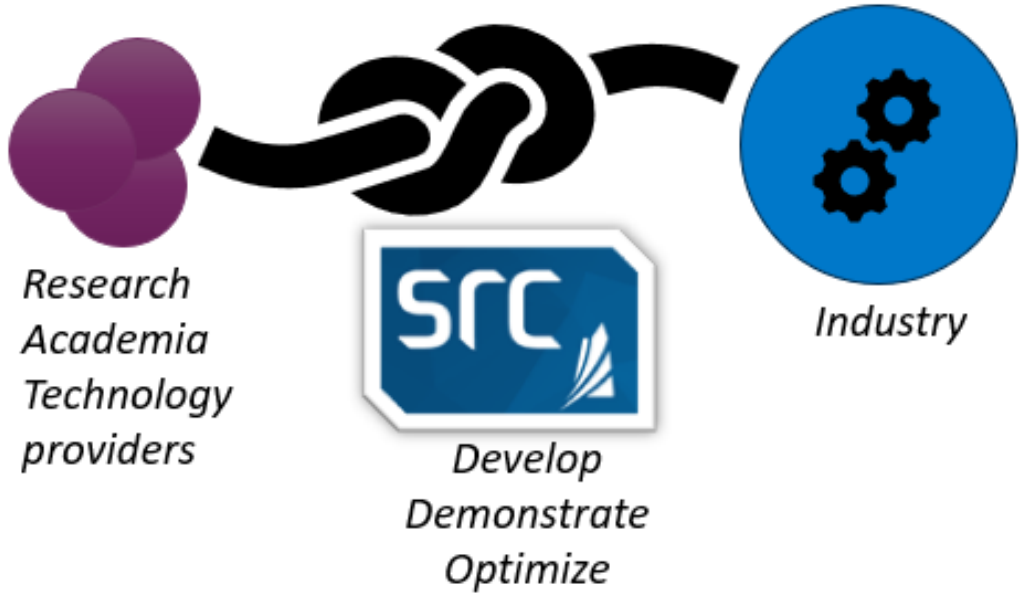
SRC Regina is situated on Treaty 4 Territory and the Homeland of the Métis.

SRC’s Project CLEANS is situated on Treaty 8 Territory and the Homeland of the Métis.

Overview

SRC (Saskatchewan Research Council) is Canada's second largest research and technology organization and has supported industry, government and communities to develop and demonstrate technology around the world for over 75 years.

SRC solves technology challenges for industry, commercialize technologies and test/validate technologies from one industry to another.



SRC HAS LOCATIONS IN

- Saskatoon, Sask. (Headquarters)
- Regina, Sask.
- Uranium City, Sask.

Proudly serving 1,600 clients across the world.

Mining Industry Services

Services that **meet industry needs** across the **mining cycle**, from **extraction to tailings**, for a wide range of minerals.

We provide **technological solutions,** testing and validation while considering **social & environmental impacts**.

Integrated approach to tackling industry challenges allows clients to bring operational needs to one location.

Outline

- Radiation Basics
- Radiochemistry
- Operations
- Closure and Remediation
- Next: Radioactivity in Mineral Exploration

Radiation Basics

- Radioactive elements are a facet of many different mining operations
- Some elements mined specifically for their radioactive properties (uranium)
- Some elements have radioactivity naturally associated with them (potash)
- Release of radioactive material in effluents and wastes can pose issues for all types of mining

Radiation Basics

Technical Language

- Radionuclides, radioisotopes, isotopes
- Decay Series
  - Decay into other (radioactive) elements
- Radioactive emissions
  - Alpha, beta, gamma
  - Other types (not discussed here)
  - Emissions (type/energy) depend on isotope

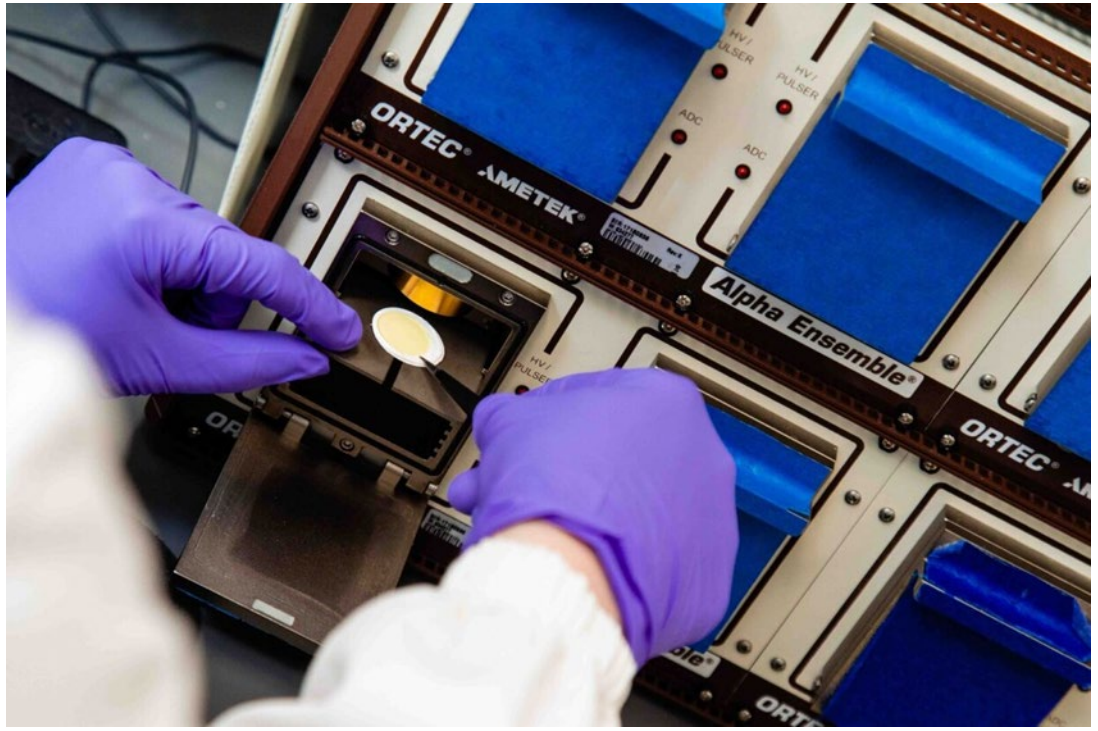
Radiation Basics

Particles or waves?

- Both of course
  - Alpha/beta often thought of as particles
  - Gamma usually thought of as wave (photons or light)
- Gamma highly penetrating
- Alpha/beta easier to stop
  - Alpha biologically most damaging - if ingested

Radiochemistry

- Type/energy of emission used to identify the isotope
- Techniques are very sensitive
  - Individual emissions represent the decay of individual atoms
- Short half-life isotopes can emit significant amounts of radiation from a very small mass
  - High Specific Activity (HSA) material (vs LSA)



Radiochemistry

- Quantities of radioactive material usually characterized by radioactivity instead of mass
  - Bq/g vs ug/g
- Becquerel (Bq) is represented by disintegrations per second
  - Related to material mass
  - Can use “specific activity” of the isotope to calculate mass

Operations

- Metal and Diamond Mining Effluent Regulations (MDMER) require environmental monitoring for certain radionuclides (Radium-226)
- Radium-226 (Ra-226)
  - Part of uranium decay series
  - Alpha emitter (stringent controls)
  - Small quantities can present issues
- Uranium mining requires monitoring for several other isotopes

Operations

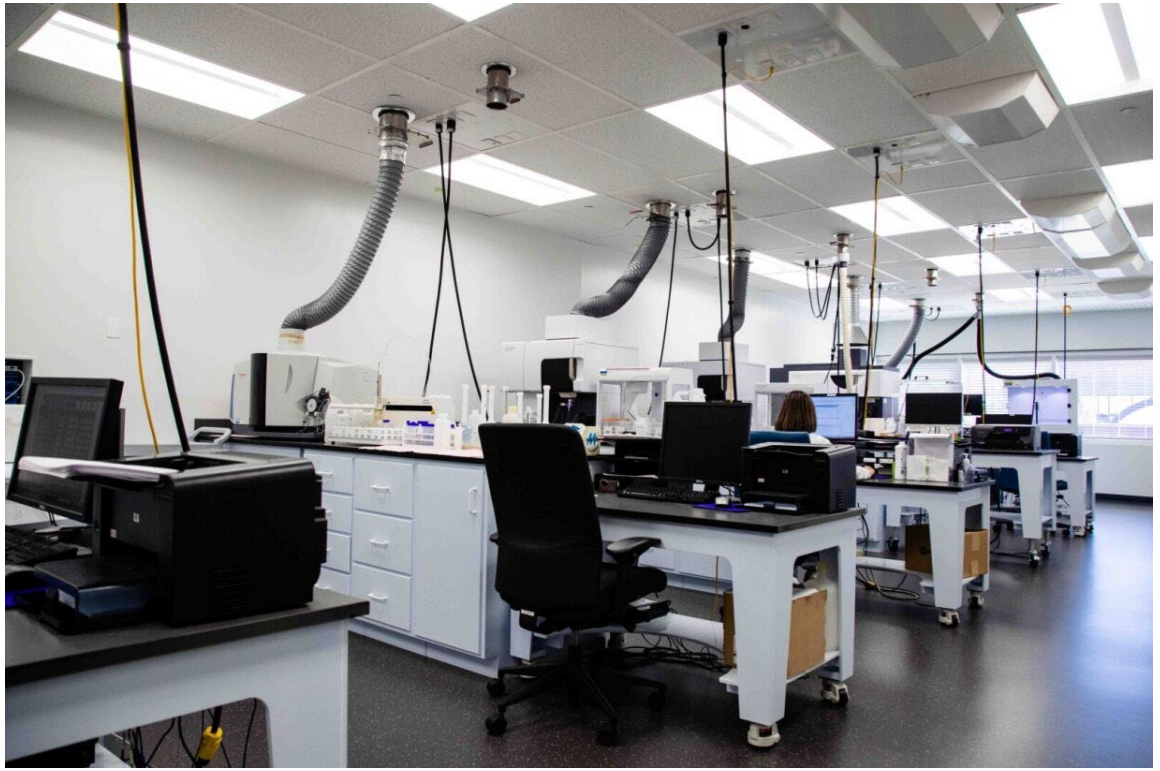
- Naturally Occurring Radioactive Materials (NORMs) can present issues in many industries, not just mining
  - Fertilizer production
  - Oil and gas
- Industrial processes can lead to unexpected or unanticipated concentration of radionuclides
  - Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)

Operations

- Transport of Dangerous Goods (TDG) Regulations
  - U mining - usually, LSA material UN 2910
  - 70 Bq/g is TDG cut-off
    - Not always possible to know concentration in Bq
- Shipping Samples
  - Licensed by the Canadian Nuclear Safety Commission (CNSC) to accept radioactive materials

Operations

- Sensitive techniques
  - Certain samples have moderately high radioactivity (e.g., sediments)
- Handling Samples
  - Lab staff always available to support clients with their needs and questions

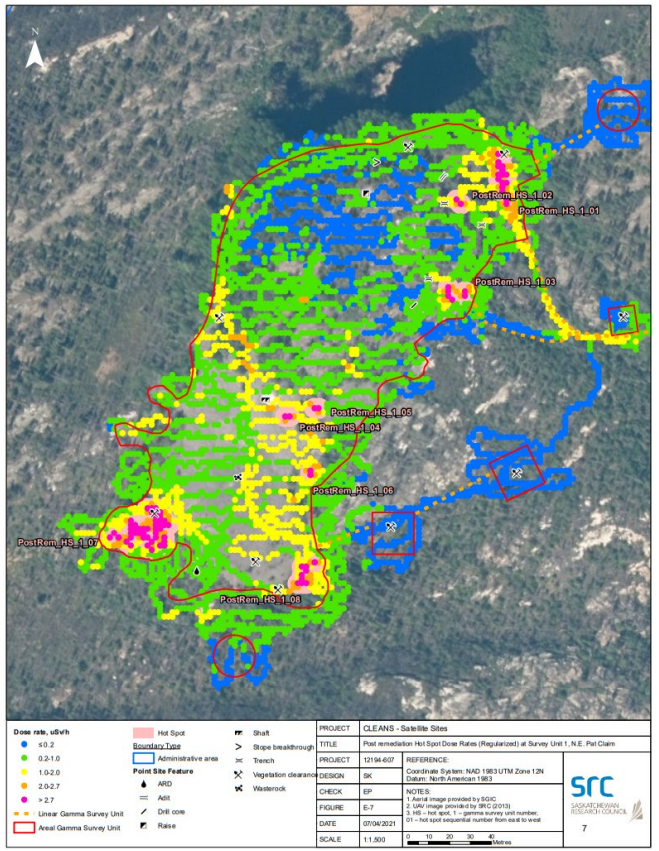


Closure and Remediation

- SRC is leading Project CLEANS (Cleanup of Abandoned Northern Sites)
  - 37 remote, abandoned uranium mine sites
  - Lack of regulation in the 1950s and no remediation led to many issues (safety/environmental)
  - Goal is to return sites to provincial control under the Institutional Control Program (ICP)

Closure and Remediation

- Project CLEANS Gamma Surveys
  - Radiation emissions provided a tool to help characterize issues
  - Initial characterization
  - Follow up during remediation process
  - Clean soil covers installed to shield gamma, then surveyed to confirm criteria met



Closure and Remediation

- Ongoing monitoring required after mine closure
- Requirements vary in different provinces
  - Saskatchewan has Institutional Control Program (ICP)
  - ICP Began in 2005
  - Formal regulatory process for long-term monitoring and maintenance when:
    - Mining/milling operations have ended
    - Remediation is complete
    - Sites ready to transfer to provincial responsibility

Summary

- Analytical techniques for radioactive materials often very sensitive
- Although radioactive materials can pose a significant concern, often their radioactive properties can yield some unique advantages

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Radioactivity in Mineral Exploration

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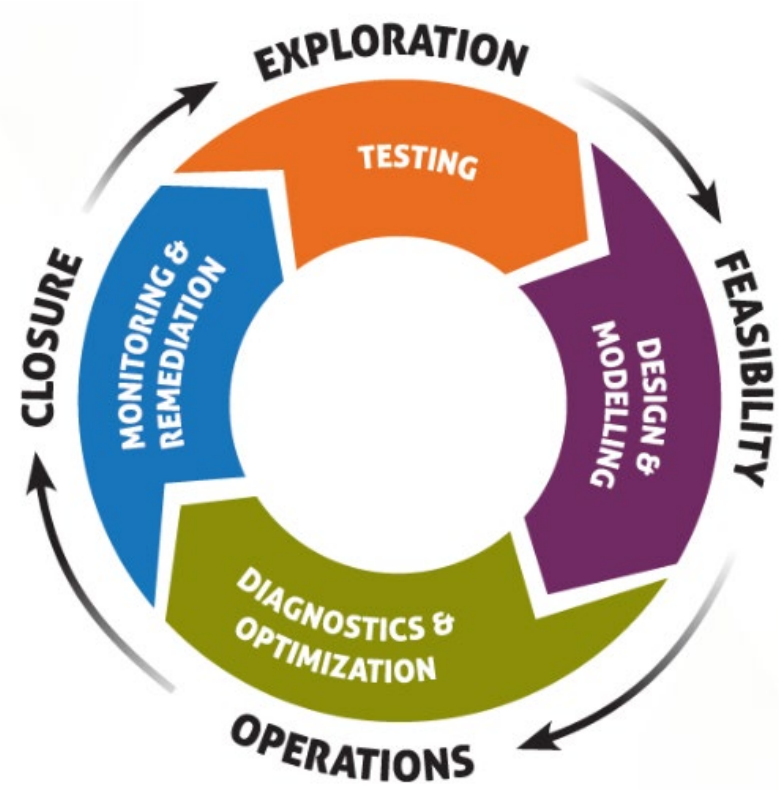
Outline

- Important radionuclides in mineral exploration
- Applications in:
  - Uranium
  - Rare Earth Elements
  - Copper Porphyry
  - Ore Sorting

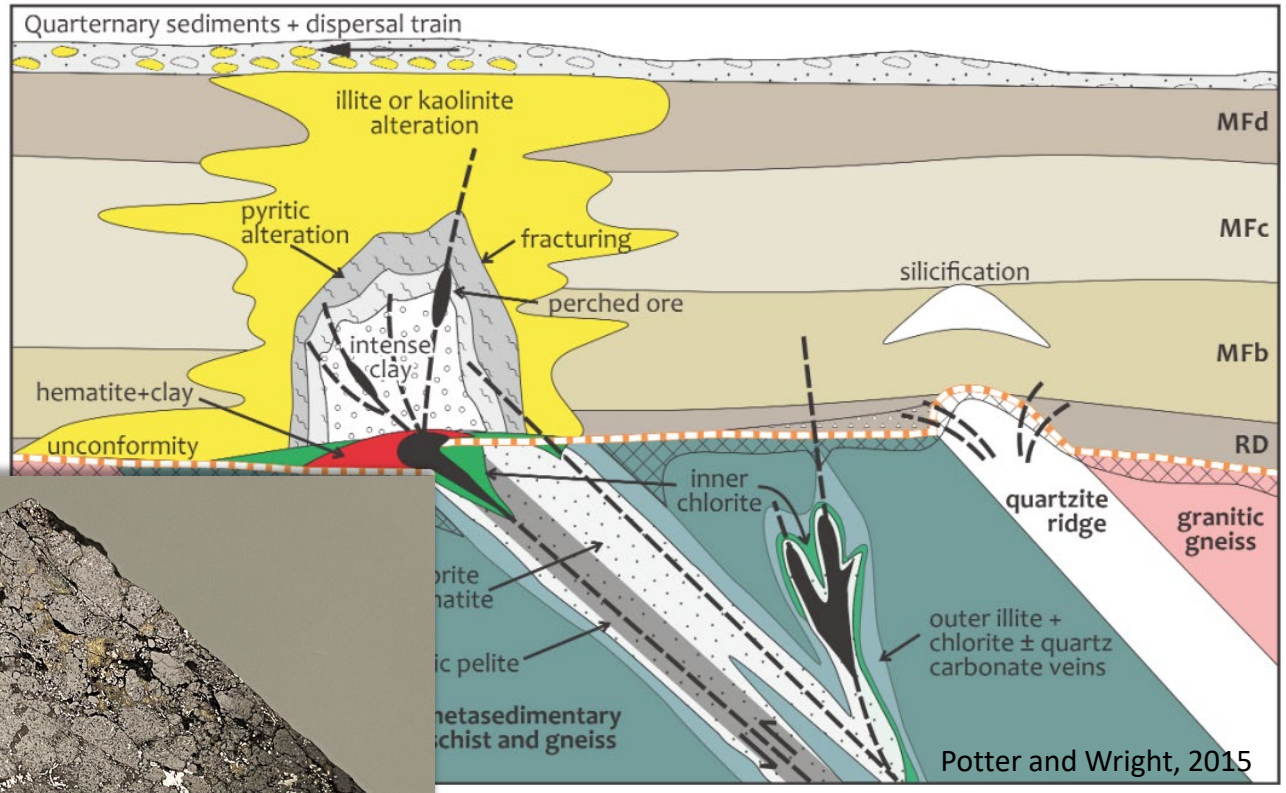


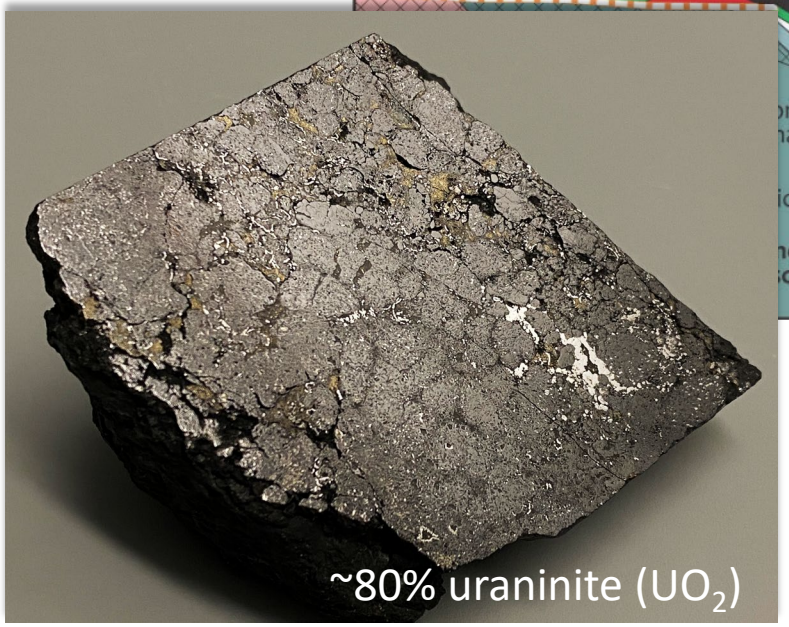
Important Radionuclides

- $^{238}U \rightarrow {}^{206}Pb$
- $^{235}U \rightarrow {}^{207}Pb$
- $^{232}Th \rightarrow {}^{208}Pb$
- $^{187}Re \rightarrow {}^{187}Os$
- $^{40}K \rightarrow {}^{40}Ar$
- $^{87}Rb \rightarrow {}^{87}Sr$
- $^{147}Sm \rightarrow {}^{143}Nd$
- $^{176}Lu \rightarrow {}^{176}Hf$

Unconformity Uranium Deposits

- Highest grade uranium deposits
  - Athabasca Basin in SK is most significant
- U daughter products detected by gamma spectrometers and Geiger detectors



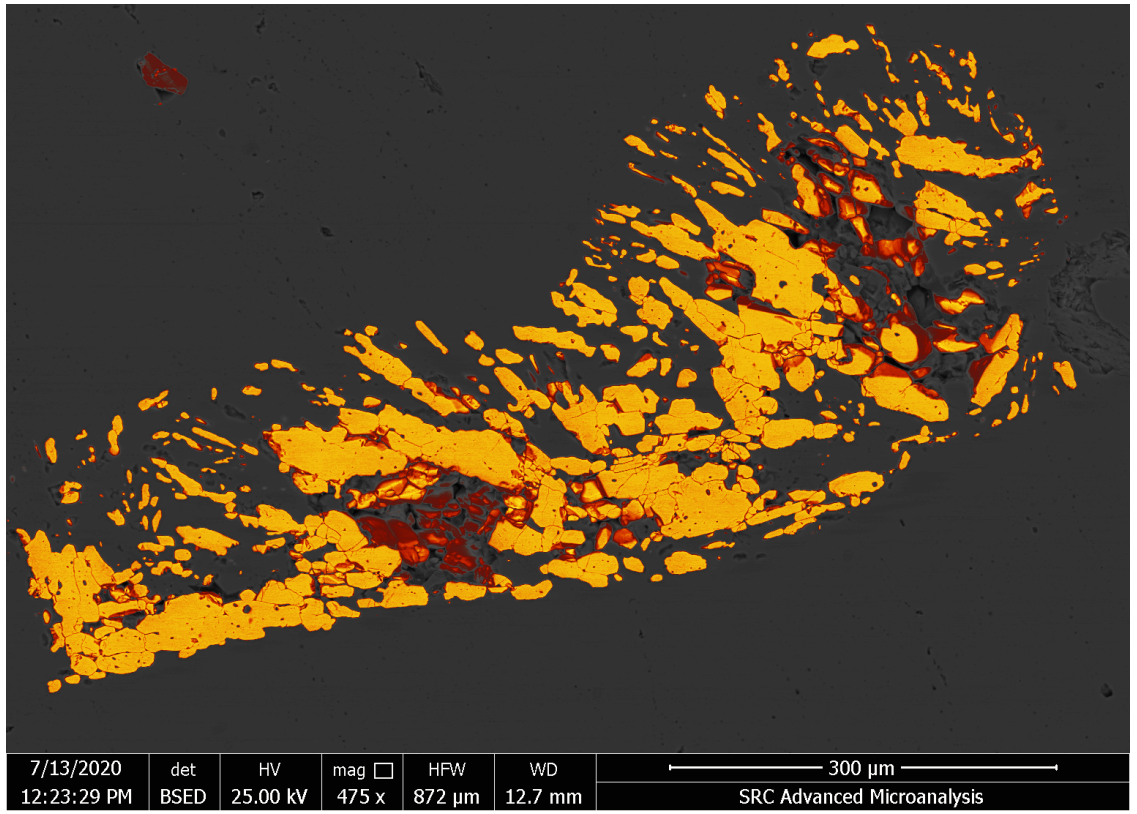


Special Considerations

- High uranium concentrations produce intense gamma radiation
  - Downhole gamma sensors require unique calibration
  - Focused SOPs required for ensuring safe-handling
  - Standards and methods for assays

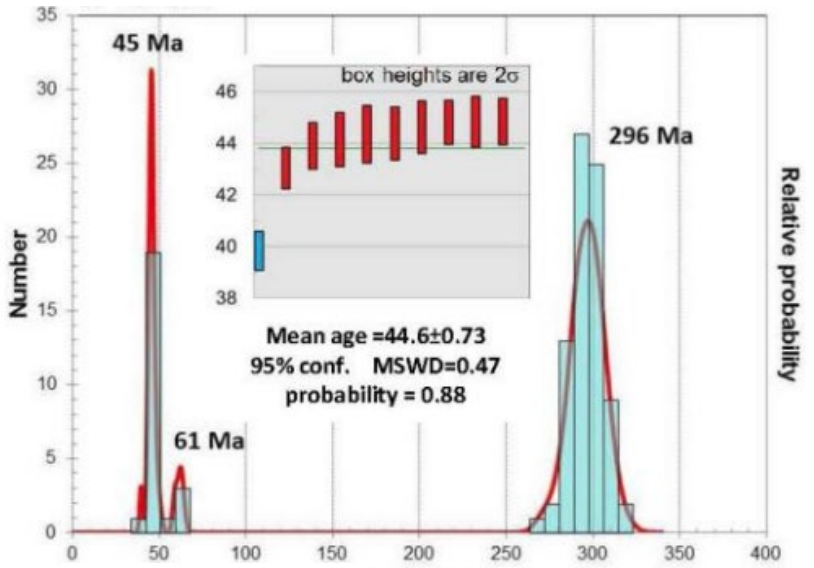
Rare Earth Elements

- Principle sources are frequently associated with thorium
  - As constituent element – e.g., monazite up to 10% ThO_2 is common
  - In secondary (alteration) minerals – e.g., thorianite and thorite
- REE ores also concentrate the radiation
- Requires similar licensing and safe-handling procedures as uranium ores

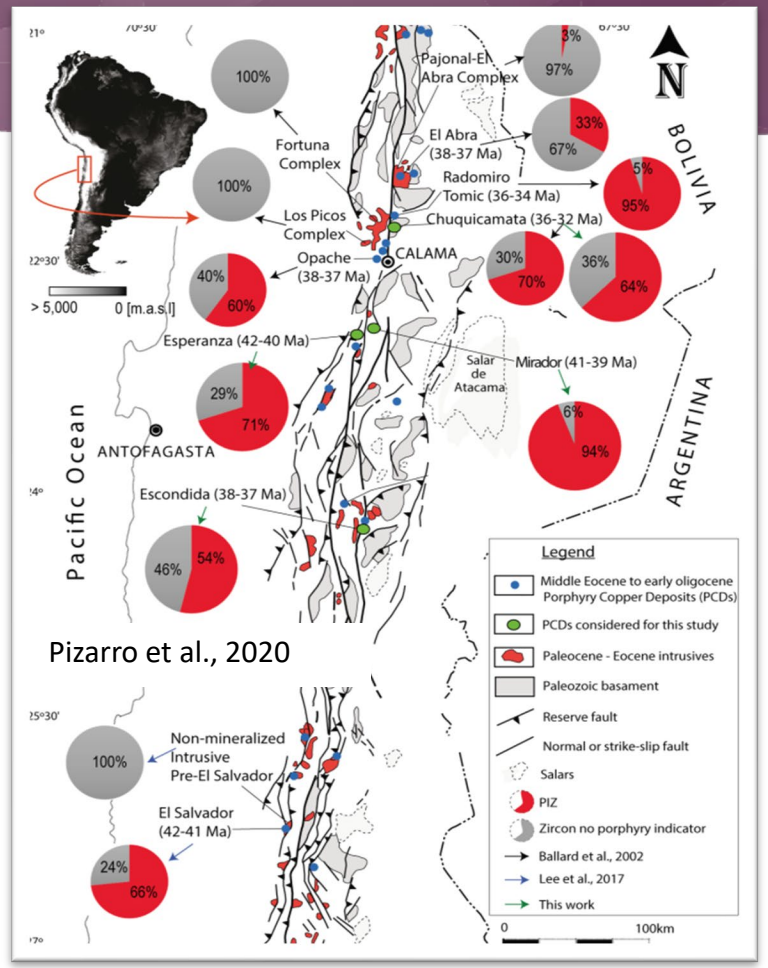


Copper Porphyry

- Identifying porphyry indicator zircons in sediments
  - U-Pb dating of zircons Centinela Mining District, Chile
  - 296 Ma zircons from barren basement rocks
  - 45 Ma zircons related to copper mineralization
  - Follow up trace-element geochemistry (PIZ)



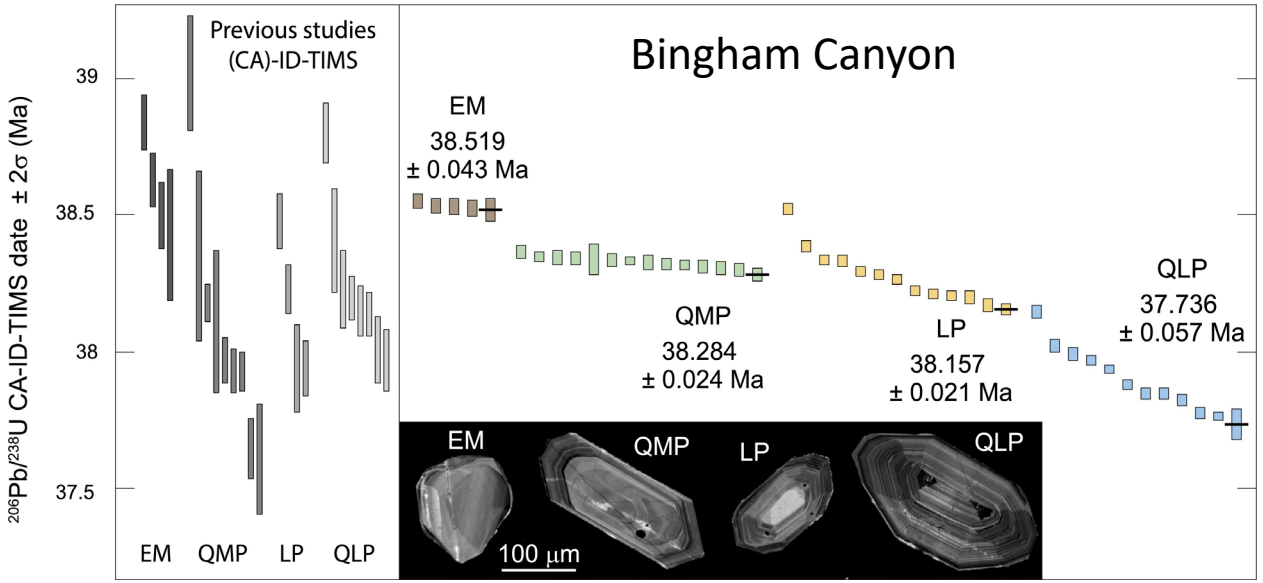
Riquelme et al., 2017



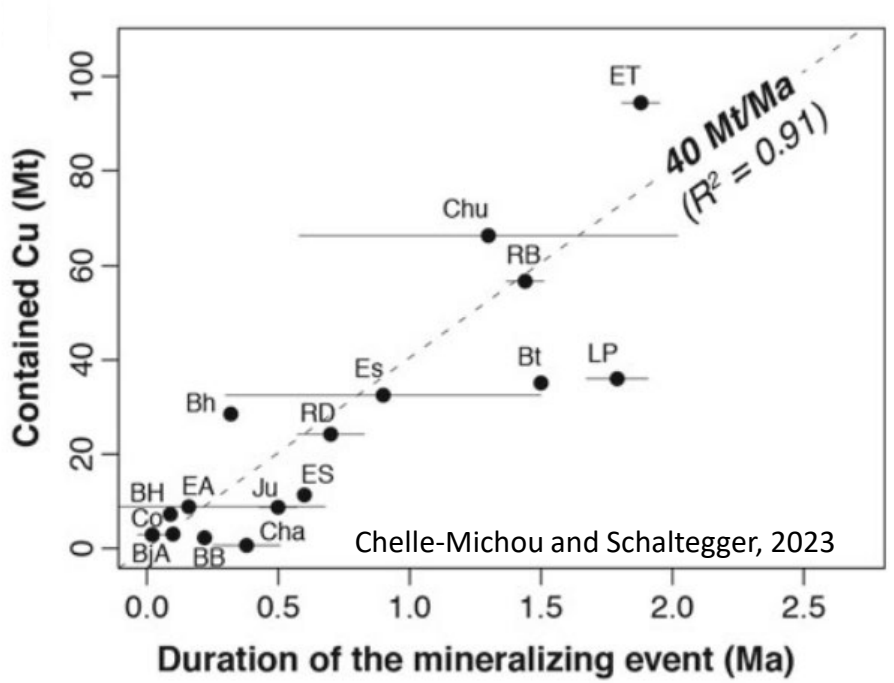
Pizarro et al., 2020

Copper Porphyry

- Duration of mineralization event(s)
- Zircon dating of porphyry events comprising single deposits
- Strong correlation between tonnage and duration



Large et al., 2021

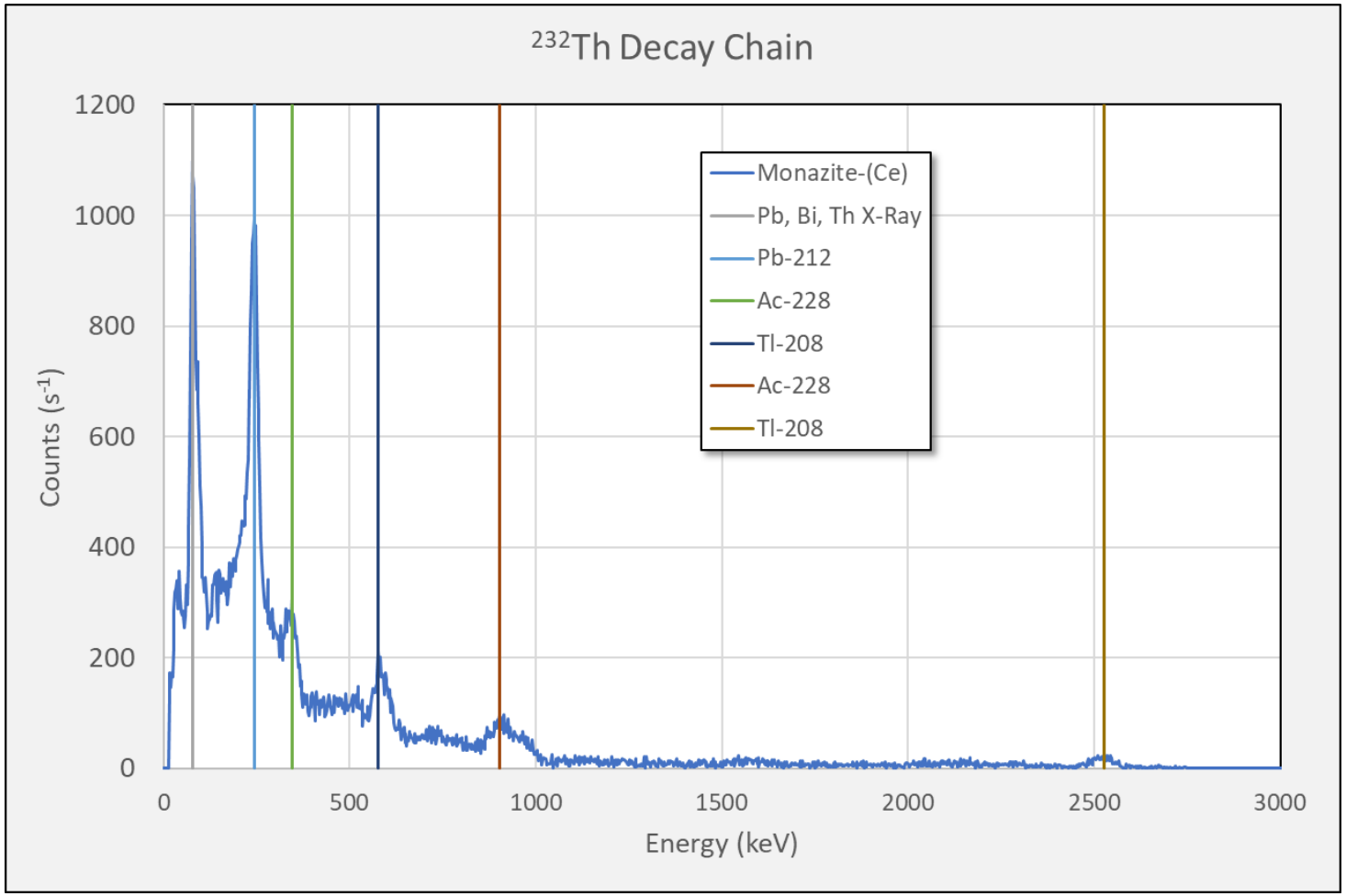


Chelle-Michou and Schaltegger, 2023

Ore Analysis and Sorting

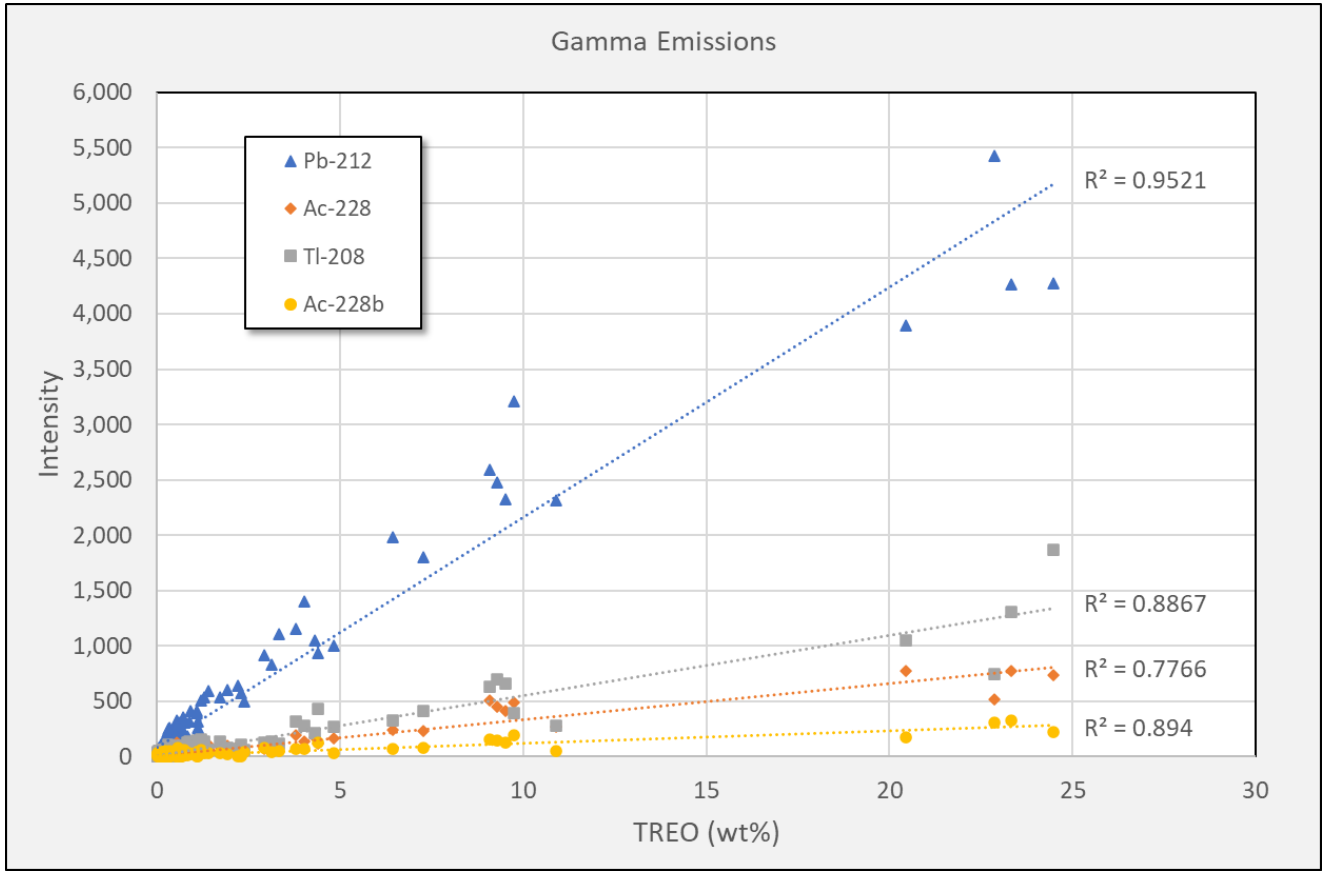
- Gamma detectors for intrinsically radioactive ores (e.g., U, REE)
- PGNAA (prompt gamma neutron activation analysis) induces short-lived radioisotopes in the sample and measures the emitted gamma
  - Multi-element assays on a conveyor belt
- Chrysos PhotonAssay™ for gold assay
  - LINAC X-Ray activation, gold isomers emit gamma rays proportional to concentration

Gamma Spectroscopy



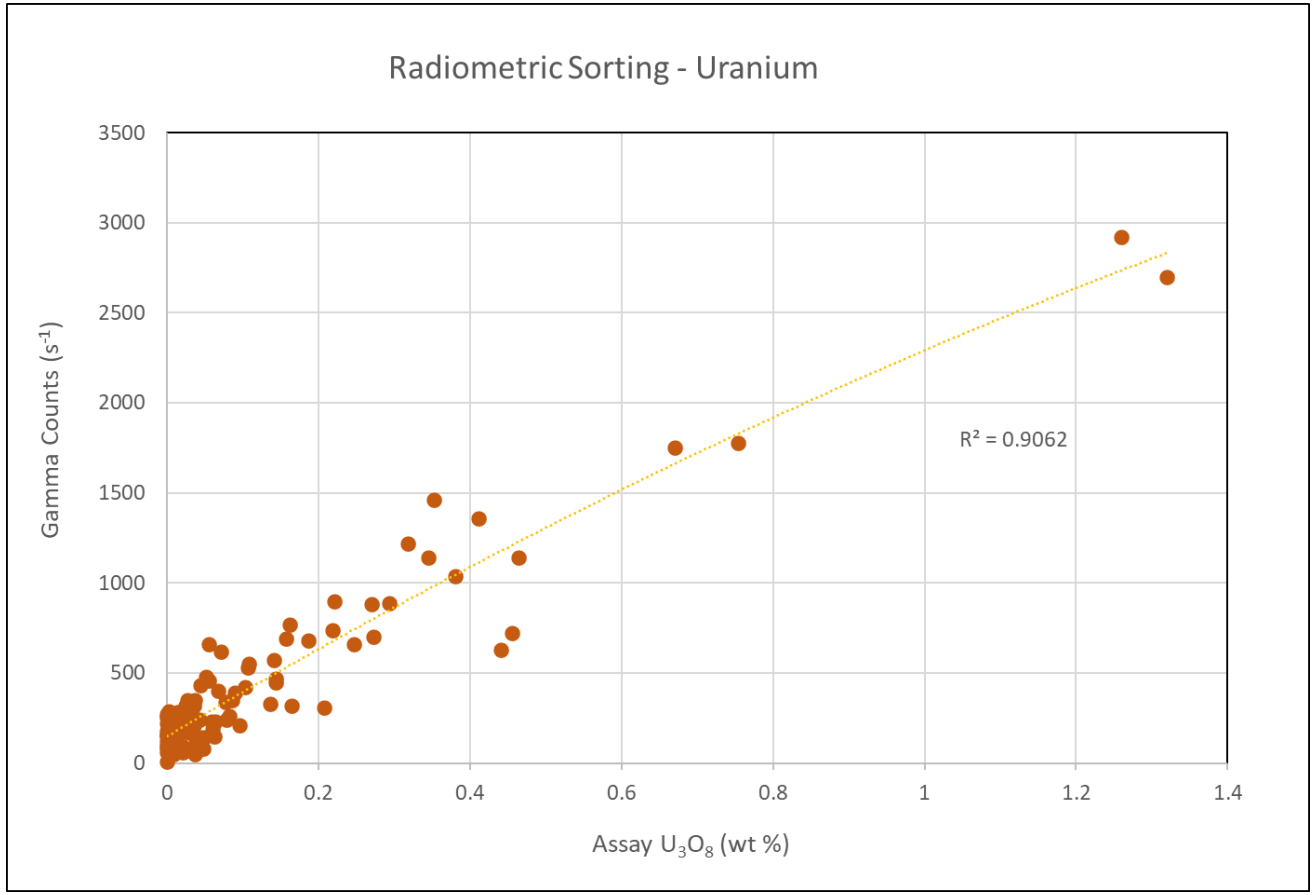
REE Ore Sorting using Gamma

^{212}Pb in ^{232}Th decay chain



Gamma Sorting - Uranium

^{214}Pb in ^{238}U decay chain



Summary

- Natural and induced radioactivity is important in mineral exploration
  - Not just the obvious case of uranium
- Unique gamma signatures can be used to identify the source of radiation
- Gamma emissions can be used to sort and concentrate various ore types

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