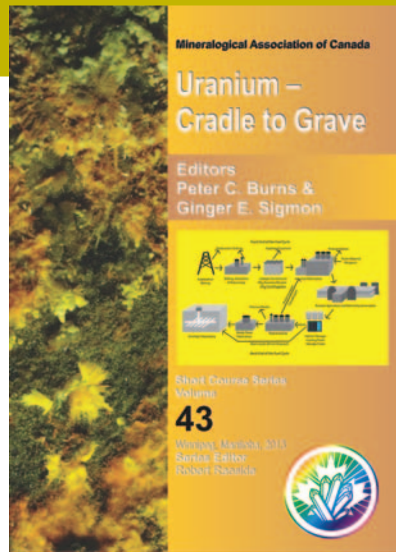
URANIUM – CRADLE TO GRAVE[1]



Uranium – Cradle to Grave, the newest volume in the Mineralogical Association of Canada Short Course Series, was developed for a short course held in Winnipeg, Canada, in May 2013. The volume provides a wide-angle snapshot of the ever-growing field of uranium research. Examining the intersection between the nuclear fuel cycle and the geochemical cycle of uranium, the volume expertly covers uranium mineralogy and geochemistry, but also provides access to topics less commonly found in the mineralogical and geochemical literature, notably nuclear nonproliferation and nuclear forensic science.

The past two decades have seen remarkable advances in uranium chemistry. Much of this progress derives from environmental research, including radioactive-waste disposal and remediation of contaminated sites. To a large extent, technology has propelled this knowledge growth, including the exponential growth in computing power. This latter factor has dramatically expanded the field of theoretical actinide science, including crystal chemistry, aqueous chemistry, and surface complexation. Advances in absorption and emission spectroscopies have also contributed greatly, proving especially powerful when combined with computational chemistry. There seems every reason to expect such progress to continue. And while *Uranium – Cradle to Grave* does not explicitly address analytical techniques, many chapters bear testament to these advances.

The volume opens with a brief historical sketch, sprightly written, though not carefully enough (for example, the author states that natural fission reactors are characterized by being abnormally enriched in ^{235}U; they are, of course, anomalously depleted in that fissile isotope). The second chapter introduces the volume's contents and provides context, including current issues related to the complex legacy of the nuclear fuel cycle for production of energy and weapons.

Krivovichev and Plášil (chapter 3) provide an excellent, well-organized review of U^{6+} mineralogy, including crystal chemistry and bonding, mineral occurrences, and structures (U^{4+} minerals are not discussed in any detail). Sections describing structural topologies, polytypism, and topological isomers, especially among uranyl phosphates, sulfates, and molybdates, are illuminated through the graphical use of anion topologies and cation nodes, bringing clarity to some otherwise complex structural features and relationships. The authors also provide links between cation coordination in the solid state and solution complexes, a good primer for chapters 6–8. Though minor, the omission of simple uranyl (hydr)oxides neglects a few new minerals: paulscherrerite, heisenbergite, and vorlanite [$(CaU^{6+})O_4$], with its apparently singular paragenesis.

Fayek (chapter 4) provides a well-written and succinct review of uranium ore deposits, including three classification schemes based on (1) host rocks (lithology and morphology); (2) ore genesis and the geologic cycle; and (3) fluid type and mineralizing system, with magmatic, metamorphic, and meteoric end-members. The diagrams are especially clear. Somewhat buried at the end is a discussion about using trace elements and stable isotopes to help identify the provenance of uranium ores. This has applications to nuclear forensic science, also discussed in chapter 13. Unfortunately, the two chapters don't refer to each other.

Navrotsky and coauthors (chapter 5) review thermodynamic studies of uranium-bearing solids, with considerable attention paid to compounds unknown in nature. The important but small number of studies on uranium minerals help emphasize the need for continued work. The authors confuse fission products and decay products, a surprising mistake.

Surface-mediated controls on geochemical transport of uranium form a common theme for chapters 6 through 8. Indeed, there is considerable overlap among these chapters (especially 6 and 8), all of which address sorption to some degree. Chapters 6 and 8 both review aqueous speciation and solution chemistry, surface-complex modeling, mineral-specific sorption, and sorption in natural sediments. Fein and Powell (chapter 6) review uranium sorption on bacteria, while Zachara and coauthors (chapter 8) describe uranium minerals in contaminated sediments. Zachara and coauthors culminate their thorough review with a case study about uranium migration at Hanford (USA). Their cautionary notes about challenges in interpreting and modeling data for experimental and complex natural systems are worthwhile reading for anyone interested in reactive-transport modeling. Schindler and Ilton (chapter 7) focus on abiotic surface-mediated reduction of U^{6+} by Fe^{2+}, followed by uranium-mineral precipitation and dissolution reactions, including coprecipitation of uranium with silica, calcite, and gypsum. These authors note that reactions at interfaces may not reflect expectations based on bulk solution chemistry, a point also mentioned in chapter 8. Schindler and Ilton end each section with a helpful summary of questions for further research.

Spent nuclear fuel and other radioactive wastes are inevitable products of the nuclear fuel cycle, and actinide-bearing waste forms destined for eventual disposal are discussed in chapters 9–12. The first three of these chapters review the most commonly considered waste forms: borosilicate glass, crystalline ceramics, and spent UO_2 fuel from nuclear power reactors. These three chapters expertly cover the most pertinent aspects of waste forms, including actinide loading, radiation stability, chemical durability, and actinide release during corrosion/dissolution. Polinski and coauthors (chapter 12) focus narrowly on structural studies of a few synthetic actinide-bearing compounds, without clear relevance to waste disposal or natural environments.

The attribution of certain nuclear materials using nuclear forensic science is the subject of chapters 13 and 14. Hutcheon and coauthors (chapter 13) review analytical methods used to analyze interdicted nuclear and radiological materials and describe two case studies. Analytical methods described here will be familiar to Earth scientists. Simonetti and coauthors (chapter 14) give a fascinating account of a forensic investigation of postdetonation nuclear materials: glassy residues of the first-ever nuclear explosion in New Mexico, USA, in 1945. The chapter reveals many complications related to extracting accurate information about a nuclear explosive device and details of a post-detonation scenario, complications likely to be compounded if such a scenario were to occur in an urban center. The volume closes with a look to the future: Cuney (chapter 15) reviews worldwide resources of uranium and thorium for potential energy production.

Uranium – Cradle to Grave is an excellent addition to the immense and ever-expanding literature on uranium, covering an unusually wide range. It is a bit uneven, with a few obvious errors and occasional inconsistencies. Although the book is already expansive, the editors might still have included other topics (theoretical studies or perhaps uranyl-peroxide nanoclusters, the omission of which I find a bit unfortunate). Several truly outstanding chapters make up, by far, the bulk of the volume. Chapters 3, 4, 8, 9–11, and 14 are especially well written, comprehensive, and just plain interesting (to me). This is and may long remain a valuable resource for researchers in a range of disciplines and should help inspire continued interest in this prodigious subject.

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1 Burns PC, Sigmon GE (eds) (2013) Uranium – Cradle to Grave. Mineralogical Association of Canada Short Course Volume 43, ISBN 978-0-921294-53-5, 449 pp, US$60/$48 for MAC members