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URANIUM MINES AND MILLS CHAPTER 2

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CHAPTER 2: URANIUM MINES AND MILLS

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ABSTRACT

This chapter will be included in a larger ASCE Committee Report. Uranium mining production is split between underground and open pit mines. Mills are sized to produce "yellowcake" concentrate from hundreds to thousands of tons of ore per day. Miner's health and safety, and environmental protection are key concerns in design. Standards are set by the U.S. Mine Safety and Health Administration, the EPA, NRC, DOT, the states, and national standards organizations. International guidance and standards are extensive and based on mining experience in many nations.

CHAPTER 2: URANIUM MINES AND MILLS

2.1 SCOPE

This chapter reviews the mining and milling of uranium ore: first, to identify key health and safety concerns; second, to identify some areas where structural design is part of the solution; and, third, to survey regulatory guidance. On the regulatory aspects, the chapter identifies leading agencies and regulations, but does not attempt to be complete in breadth of coverage nor in detail. It is hoped that the cited references and regulations will provide an introduction and an overview picture of the main problems and solutions in this area.

2.2 FACILITY DESCRIPTION

2.2.1 Mines

Uranium is mined from both open pit and underground mines. In the United States there are more underground mines by a ratio of four to one, although slightly more than half of the uranium production comes from the open pit mines. In projections of increased uranium demand in the coming decades, underground mining is expected to increase its production share.^[1]

About 58 percent of the non-communist countries' uranium production comes from outside the U.S.^[2] Other leading countries are Canada, South Africa, Namibia, Niger, Gabon, France and Australia.

The mines are in many respects similar to other metal mines. One difference is the quantity of radioactive radon gas, which brings a requirement for more fresh air ventilation. Ground water inflow and hence the need for its drainage is usually a substantial problem, because many uranium ores worked to date occur in a sandstone matrix, and sandstone is usually permeable to ground water.

The mine shaft may be concrete lined. The hoist headframe is a steel structure. The underground geology and tunnel support techniques are important for mine stability and for groundwater and radon gas control.

Transport of the ore to the mills is usually by open truck, rail or conveyor belt.

2.2.2 Mills

Uranium mills are fewer in number than the mines. In the United States in 1978 there were 27 conventional mills, compared to over 300 mines. For reasons of economy in ore transport the mines and mill must be fairly close. Hence a large ore deposit may be developed with its own mill. A primary siting requirement for the mill is the location nearby of a suitable site for mill tailings disposal.

The mills are large steel frame structures, with capacities ranging from 400 to 7000 tons of ore per day. The structure is enclosed and the floor is concrete for easy washdown.

The uranium is extracted and concentrated into "yellowcake" assaying 70-90 percent U_3O_8 by weight (see References 3-9). The extraction efficiency from the ore is 90-95 percent. The process is adapted to the uranium mineralization, ore matrix, and impurities soluble during leaching, but generally has the following steps:

1. size reduction--ore crushing, sampling, storage in blending bins, milling in a rod mill, ball mill or cascade mill. Transport between steps is usually by conveyor belt;
2. wet leaching by an acid or alkaline agent;
3. settling of the sand-size and fine solids, filtering and clarification of the liquid;
4. product recovery from the liquid by some combination of ion exchange using anion resin columns, organic solvent extraction, and chemical precipitation, and
5. extraction, drying (and in some cases calcining), and packaging of the yellowcake precipitate.

The steps with large material volume are the crushing, milling and the steps using the first solution phase--the leaching, solids settling and the first ion exchange step. The acid liquid is recycled to the leaching step.

One mill as an example may illustrate the size of the equipment and structures. The mill in the Shirley Basin of Wyoming^[10] is designed for 1200 short tons per day. The crushing step is bypassed. Run-of-mine ore is introduced to an 18 foot diameter by 6 foot long cascade type mill. Further equipment includes storage tanks, two stages of leaching tanks and solids thickening and settling tanks, clarifying beds, ion exchange columns, storage and settling tanks, centrifuges, dryers and an enclosed hopper for the packaging operation. Except for the six 100 foot diameter thickener vessels, all other pieces of equipment are contained within one building structure, 427 feet long and 190 feet wide.

With ores averaging 0.12 percent of uranium oxide or equivalent, most of the ore becomes waste tailings. The tailings are transported to the tailings pile via slurry pipeline, using some of the spent processing water as the slurry liquid. Excess wastewater is piped to evaporation ponds.

In semi-arid areas such as the copper and uranium mining areas in the Western United States and the South African gold mining districts^[11] tailings dams can be built up in part using the coarse fraction of the tailings. For uranium mill tailings most of the radium in the liquid fraction can be precipitated out by pH control and barium chloride addition. Important factors in tailings site selection and design are tailings dam foundation and stability, seepage control, and a topography which, together with postclosure sealing and ground cover, will be conducive to long term stability of the tailings materials.^[12,13] In some cases a below-grade tailings pit or disposal in mined-out areas may be preferred, when the latter is not incompatible with the mining method. In one northern Canadian district^[14] where the evaporative potential over the year is small, a combination is used of return to the mine and settling of tailings in a dedicated pond. The

coarse fraction of the tailings is separated for use as mine backfill, and the fines and liquid fractions are treated in a series of ponds by settling and chemical precipitation, thereby reducing the radium content of the treated water to below one-fifth of the federally allowed limit before the water is released to an open lake.

The yellowcake product is usually packed in 55-gallon drums or sealed bulk containers for shipment by truck, rail, or air to a uranium conversion facility where it will be further purified and converted to UF_6 .

Unconventional methods, i.e., in-situ leaching, heap leaching, or byproduct recovery from copper or phosphate mines, contribute less than 10 percent of the U.S. uranium production.^[1,9,15] Their contribution will increase as small isolated deposits or low grade ores become economically in demand.

2.3 GENERAL REQUIREMENTS

The principal health and safety problems requiring design attention are: (1) the health of the workers, and (2) controlling the release into the environment of the natural radioactive materials found with the uranium ore, especially securing the tailings disposal site over both the short and long term. Ease of decontamination and decommissioning (D&D) of the mill site must also be a factor in its design, since the mill will operate for perhaps only fifteen or twenty years, depending on the local ore reserves.

Radon gas and its decay products present a potential health hazard, particularly for underground miners. Radon, the decay product from radium, can percolate through fractured or porous rock into the mine atmosphere. When it decays, its product attaches preferentially to dust particles or else to the mine wall. Fine inhaled dust can be retained. Thus, great attention is given to the age of the air in the mine, requiring much greater ventilation capacity than in other mines. Dust control is also important, as are sealing

of the mine walls and mined-out areas, and not keeping much inventory of broken-up ore in the mine. Control of radon and radon-daughter products in mine atmospheres is reviewed in Reference 16.

For open pit mines, the natural air circulation is very helpful in limiting radon buildup. Dust control is emphasized as in other types of mining.

In the mills, the yellowcake product with more than 70 percent uranium oxide is often a fine powder. (Calcining, used in some mills, produces a denser and larger grained powder.) The feed ore is more dilute but contains uranium decay products. To control dust, enclosed operations and wet processing are used. Both enclosed dry and wet milling of the ore are in use. Succeeding steps up to product drying are in a liquid medium, so dust control just involves spill control or cleanup. Particular attention is paid to the drying and packaging process enclosure and stack emission control. The mills have concrete floors with conveniently located sumps for easy washdown of the plant. Air filtering systems are also used.

The off-site public is protected by limiting the release of radioactive materials to the environment. Solid tailings are disposed of where their materials can be contained. Water seepage and dust control and long term stability are criteria for the location, design and operating procedures. Mine drainage water is treated or used as mill process water. The exhaust air meets radioactivity limits by limiting the sources of radon and by dust filtering.

Mine tailings have more volume but less radioactivity than mill tailings, and hence are a lesser hazard to the public. The mine tailings include overburden or waste rock from tunnels, and sub-ore which contains a small amount of uranium and its decay products.^[9,17] Much of the tailings is used as mine backfill. In open pit mines, tailings are used to refill spent pits; the least uranium-bearing overburden is replaced on the top. Sealing and surface revegetation are used.

Mill tailings receive most of the ore's radioactivity, i.e., the uranium decay products.^[9,15] As mentioned in the preceding section, the mill tailings disposal requires design for both operating and long-term stability, limiting radon gas release at the surface, radium release via water percolation, and mass release via windblown dust or waterborne erosion. Tailings dam construction is a key element. Post-closure surface sealing with asphalt is sometimes used, and a dirt layer is applied on top of the tailings pile.

2.4 DESIGN CRITERIA, CODES AND STANDARDS

2.4.1 Regulatory Sources

Miners Health and Safety - The Mine Safety and Health Administration (MSHA), Department of Labor sets standards for mining safety and limits the exposure of miners to radon and radon daughters. The standards are in the U.S. Code of Federal Regulations (CFR):

30CFR55	Health and safety standards - metal and nonmetallic open pit mines
30CFR57	Health and safety standards-metal and nonmetallic underground mines

The radon daughters limit is based in part on guidance from the Environmental Protection Agency^[16] and earlier recommendations of the Federal Radiation Council.^[18]

Uranium Mills - The EPA^[19] provides general standards for environmental radiation protection covering the uranium fuel cycle from mills through power plant operation and possible reprocessing and recycling of uranium:

40CFR190	Environmental radiation protection standards for nuclear power operations

The NRC is responsible for mill licensing, radiological health and safety in mills, and for ensuring that each mill will meet the EPA environmental standard. The MSHA also has responsibilities for occupational health and safety at mills; NRC and MSHA coordinate their roles. NRC sections of the Code of Federal Regulations relevant to uranium mills include:

- 10CFR20 Standards for protection against radiation
- 10CFR30 Rules of general applicability to domestic licensing of byproduct material
- 10CFR40 Domestic licensing of source material
- 10CFR51 Licensing and regulatory policy and procedures for environmental protection
- 10CFR150 Exemptions and continued regulatory authority in agreement States and in offshore waters under section 274

Especially note 10CFR40 on licensing, since "source material" includes mined uranium ore and yellowcake; and 10CFR40 Appendix A which presents criteria relating to the operation of uranium mills and the disposition of tailings. In "agreement states", covering most of the mining regions, the states administer the NRC regulatory authority on mills and mill tailings.

The Department of Transportation provides the main regulations on transport of the yellowcake, under its hazardous materials regulations:

- 49CFR173 Shippers-General requirements for shipments and packagings

The Uranium Mill Tailings Radiation Control Act of 1978 has expanded regulation for tailings piles from active mills, as well as inactive uranium processing sites and tailings piles. This is leading to revised EPA and NRC regulations.^[20,21]

2.4.2 International Guidance

Since uranium mining and milling is done in many countries, international guidance on health and safety embodies extensive experience which can prove helpful to domestic projects. Here we make note of References 22-28.

2.4.3 Regulatory Guides

NRC regulatory authority covers uranium mills and mill tailings piles, but not mines. Of the ten subject areas of NRC regulatory guides, the areas most relevant to uranium mills are:

Division 3: Fuels and Materials Facilities

Division 4: Environmental and Siting

Division 8: Occupational Health

Regulatory guides include:

R.G. 1.59	Design Basis Floods for Nuclear Power Plants
R.G. 3.5	Standard Format and Content of License Applications for Uranium Mills (For Comment)
R.G. 3.8	Preparation of Environmental Reports for Uranium Mills (For Comment)
R.G. 3.11	Design, Construction, and Inspection of Embankment Retention Systems for Uranium Mills
R.G. 3.11.1	Operational Inspection and Surveillance of Embankment Retention Systems for Uranium Mill Tailings (For Comment)
R.G. 3.23	Stabilization of Uranium-Thorium Milling Waste Retention Systems

R.G. 4.14	Radiological Effluent and Environmental Monitoring at Uranium Mills
R.G. 4.15	Quality Assurance for Radiological Monitoring Programs (Normal Operations) - Effluent Streams and the Environment
R.G. 8.10	Operating Philosophy for Maintaining Occupational Radiation Exposures as Low as is Reasonably Achievable
R.G. 8.15	Acceptable Programs for Respiratory Protection
R.G. 8.22	Bioassay at Uranium Mills

Draft regulatory guides include:

Draft R.G. OH 710-4	Health Physics Surveys in Uranium Mills
Draft R.G. OH 941-4	Information Relevant to Ensuring That Occupational Radiation Exposures at Uranium Mills Will Be as Low as is Reasonably Achievable
Draft R.G. RH 802-4	Calculational Models for Estimating Radiation Doses to Man from Airborne Radioactive Materials Resulting from Uranium Milling Operations
Draft R.G. FP 818-4	Standard Format and Content of License Applications, Including Environmental Reports, for In Situ Uranium Solution Extraction

2.4.4 National Standards

Of particular relevance are:

ANSI N13.8	Radiation Protection in Uranium Mines Operation (1973)
ANSI N313	Stabilization of Uranium-Thorium Milling Waste Retention Systems(1974)
UBC	Uniform Building Code - (International Conference of Building Officials)
ACI-318	Building Code Requirements for Reinforced Concrete
AISC	Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings

2.4.5 State and Local Environmental Standards

The Federal Water Pollution Control Act, administered by the states, governs liquid effluents. Under Section 401, the facility must obtain a state certification that any discharge will comply with applicable effluent limitations and other water pollution control requirements. The facility may also be required to obtain a National Pollution Discharge Elimination System (NPDES) permit to discharge effluents to navigable streams under Section 402 of the Act.

2.4.6 Design Criteria

Criteria relating to tailings disposal design and to operation of yellowcake drying and packaging in the mill are given in 10CFR40 Appendix A and in R.G. 3.11. Other aspects of mill design are not as sensitive or unusual; design load criteria and national standards such as those presented

in Chapter 3 of this document, for uranium conversion facilities, may be used as appropriate. The environmental effects of possible accidents, for example those which might arise from a tornado or other rare act of nature, must be analyzed and presented in the Environmental Report.

10CFR40 Appendix A gives site selection criteria for tailings disposal sites. Placement below grade, in the mine or in pits, is the preferred option. Where that is not practicable, or not the most environmentally sound approach because of local conditions, then above grade disposal may be used if it will provide reasonably equivalent isolation of the tailings.

The tailings retention system must be designed for a probable maximum flood series. The design capacity relates to the diversion system for the upstream catchment area combined with an emergency spillway and a surcharge storage capacity of the tailings retention system. In site selection, the upstream catchment area should be minimized to limit both floods and long term erosion potential.

The tailings retention embankment must be designed for seismic stability, limiting or preventing settlement, displacement, liquefaction and shear failure. References are provided in R.G. 3.11 (also see Reference 29). In site selection, the impoundment may not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. "Capable fault" is as defined in 10CFR100 Appendix A. "Maximum credible earthquake" is defined in 10CFR40 Appendix A.

For the yellowcake drying and packaging operation, 10CFR40 Appendix A requires emission controls and monitoring; and cessation of operations when necessary. No increases in design loads are required.

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APPENDIX A

GLOSSARY OF TERMS AND ACRONYMS

calcining	Heating a substance to a high temperature, causing loss of moisture and impurities or causing oxidation.
mill	The Mine Safety and Health Administration defines this essentially as any facility for crushing, processing or concentrating ores at or in connection with a mine. The NRC has an extended definition of "uranium milling" as any activity that results in the production of tailings or wastes in the extraction or concentration of uranium from uranium ore; this includes unconventional processes such as waste heap acid leaching.
radon daughters	Products in the decay chain of radon. They are radioactive except for the final member in the chain. Radon-222 (half-life 3.8 days) generates in succession Polonium-218 (half-life 3 min.), Lead-214 (27 min.), Bismuth-214 (20 min.), Lead-210 (22 years), followed by Bismuth-210, Polonium-210 and stable Lead-208.
short ton	2000 pounds; a metric ton is 1000 kg.
tailings	The solid or predominantly solid residual material after uranium mining or milling. Mine tailings include overburden, waste rock excavated for shafts and sub-commercial uranium-bearing rocks. Mill tailings are the sand and more finely ground ore rock and residual radioactive elements after extraction of the uranium minerals.
yellowcake	A concentrate from uranium ore, usually as an oxide or salt of uranium, containing 70-90 percent of U ₃ O ₈ or equivalent.

Acronyms:

ACI	- American Concrete Institute
AISC	- American Institute for Steel Construction
ANSI	- American National Standards Institute
CFR	- Code of Federal Regulations
DOT	- Department of Transportation
EPA	- Environmental Protection Agency
FR	- Federal Register
IAEA	- International Atomic Energy Agency
ICRP	- International Commission on Radiological Protection
ILO	- International Labor Organization
INFCE	- International Nuclear Fuel Cycle Evaluation
MSHA	- Mine Safety and Health Administration
NEA	- Nuclear Energy Agency (of OECD)
NRC	- U.S. Nuclear Regulatory Commission
OECD	- Organization for Economic Cooperation and Development
RG	- Regulatory Guide (NRC)

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