

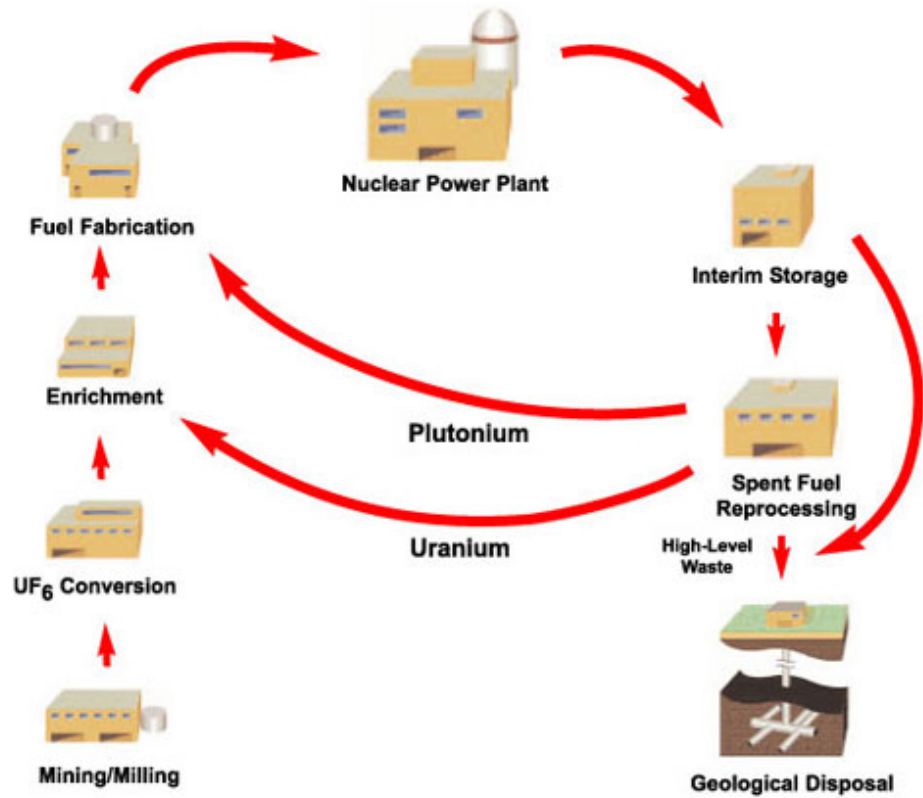
OVERVIEW OF THE NUCLEAR FUEL CYCLE AND ITS CHEMISTRY

SHORT COURSE : Introduction to Nuclear Chemistry and Fuel Cycle Separations

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THE NUCLEAR FUEL CYCLE



MAJOR ACTIVITIES OF THE FUEL CYCLE

- **MINING, MILLING, CONVERSION TO UF₆**
- **REACTORS AND FUELS**
- **SPENT FUEL REPROCESSING**
 - **AQUEOUS**
 - **NON-AQUEOUS**
 - **EQUIPMENT**
- **WASTE FORMS AND WASTE MANAGEMENT**
- **MODELING AND SIMULATION**

MAJOR ACTIVITIES OF THE FUEL CYCLE

(CONTINUED)

- **RADIATION-INDUCED DAMAGE**
 - **ORGANIC PROCESS REAGENTS**
 - **MATERIALS OF CONSTRUCTION**
- **NON-PROLIFERATION**
- **TRANSPORTATION, STORAGE AND DISPOSAL**
- **QUANTIFYING RISK OF RECYCLE FACILITIES**
- **ENVIRONMENTAL ASSESSMENT**

MINING, MILLING, CONVERSION AND ENRICHMENT

- **MINING**

- **AVAILABLE ORES**

- **OXIDIZED U (U^{+6})**

- **REDUCED U (U^{+4})**

- **CONVENTIONAL MINING**

- **IN SITU MINING (DIMINISHED ENVIRONMENTAL IMPACT)**

- **MILLING**

- **METHODS**

- **PURITY OF PRODUCT**

MINING, MILLING, CONVERSION AND ENRICHMENT

(CONTINUED)

- **PURIFICATION OF ORE CONCENTRATE**
 - SOLVENT EXTRACTION
 - UF_6 DISTILLATION
- **CONVERSION TO UF_6**
- **ENRICHMENT METHODS**
 - GASEOUS DIFFUSION (UF_6)
 - GAS CENTRIFUGATION (UF_6)
 - CHEMICAL EXCHANGE
 - AERODYNAMIC ($\text{UF}_6 + \text{H}_2$ CARRIER GAS)

REACTORS

- **MAJOR POWER REACTOR TYPES**
 - **WATER COOLED AND MODERATED**
 - LIGHT WATER: PWR, BWR
 - HEAVY WATER: CANDU
 - **GAS COOLED**
 - CO₂
 - He (HTGR)
 - **LIQUID METAL COOLED (NOT COMMERCIALIZED)**
 - Na AND ALKALI METAL EUTECTICS
 - Pb et alia
 - **MOLTEN SALT COOLED AND MODERATED (NOT COMMERCIALIZED)**

REACTOR FUELS

- **WATER-COOLED**
 - **UO₂ PELLETS IN ZIRCALOY TUBES**
- **GAS-COOLED**
 - **UO₂ PELLETS IN ZIRCALOY OR STEEL TUBES**
 - **U CARBIDES AND OXYCARBIDES IN GRAPHITE**
 - **PRISMATIC GRAPHITE BLOCKS**
 - **GRAPHITE BALLS**

REACTOR FUELS

(CONTINUED)

- **LIQUID METAL**
 - **UO₂ PELLETS IN STEEL TUBES**
 - **U/Zr/PU ALLOY IN STEEL TUBES (UNDER DEVELOPMENT)**
 - **U CARBIDE (UNDER DEVELOPMENT)**
 - **U NITRIDE (UNDER DEVELOPMENT)**
- **MOLTEN SALT**
 - **UF₄ + ALKALI METAL FLUORIDES (AND ZrF₄)**

SPENT FUEL REPROCESSING

- **AQUEOUS METHODS**

- **PUREX (TRI-n-BUTYL PHOSPHATE EXTRACTANT + NITRIC ACID SOL'N. OF SPENT FUEL)**
- **EARLIER PROCESSES**
 - **REDOX**
 - **MISC.**

- **NON-AQUEOUS METHODS**

- **PYROPROCESSES**
- **VOLATILITY (USING HALIDES, e.g., F AND Cl)**
- **DUPLIC-TYPE PROCESSES (LOW DECONTAMINATION)**

SOLVENT EXTRACTION EQUIPMENT

- **TYPES OF EXTRACTION EQUIPMENT**
 - **MIXER SETTLERS**
 - **COLUMNS**
 - **PULSE**
 - **PACKED**
 - **CENTRIFUGAL CONTACTORS**

SOLVENT EXTRACTION EQUIPMENT (CONT.)

- **BASIC SOLVENT EXTRACTION
STEPS**
 - **EXTRACTION**
 - **SCRUBBING**
 - **STRIPPING**

SOLVENT EXTRACTION EQUIPMENT (CONT.)

- **SX EQUIPMENT REQUIREMENTS**
 - **HIGH CAPACITY**
 - **OPERABLE IN RADIOACTIVE ENVIRONMENT – RADIATION RESISTANT**
 - **REMOTELY OPERABLE**
 - **REMOTELY MAINTAINABLE**
 - **CAPABLE OF HANDLING SOME SOLIDS**

OTHER IMPORTANT SEPARATIONS PROCESSES: PRECIPITATION AND CRYSTALLIZATION

- **MOST ELEMENTS FORM USEFUL PRECIPITATES**
- **FIRST Pu SEPARATION USED CARRIER PRECIPITATION**
- **Pu AND U MAY BE PURIFIED BY PEROXIDE PRECIPITATION**

OTHER IMPORTANT SEPARATIONS PROCESSES: PRECIPITATION AND CRYSTALLIZATION

(CONTINUED)

- **PRECIPITATION HAS USES AND LIMITATIONS**
 - **OFTEN NOT SELECTIVE ENOUGH FOR RADIOCHEMICAL PURITY NEEDS**
 - **CAN PRODUCE SOLIDS DIFFICULT TO HANDLE (GELATINOUS)**
 - **OFTEN USED FOR SCAVENGING IMPURITIES**
 - **Fe(OH)₃ IS A WIDELY USEFUL SCAVENGER**
 - **PHOSPHATES ARE USEFUL SCAVENGERS**

OTHER IMPORTANT SEPARATIONS PROCESSES: PRECIPITATION AND CRYSTALLIZATION

(CONTINUED)

- **CRYSTALLIZATION ENHANCES PURITY**
 - **CRYSTALS REJECT MANY IMPURITIES FROM THEIR LATTICE**
- **ACTINIDES IN THE SAME VALENCE STATES MAY CO-PRECIPITATE**

MODELING AND SIMULATION (M&S)

- **FUEL CYCLE PROCESSES LEND THEMSELVES TO M&S**
 - **MINING AND MILLING**
 - **REPROCESSING**
 - **WASTE FORM DESIGN**
 - **WASTE STORAGE AND DISPOSAL**
 - **ACCIDENT SIMULATION**
 - **TRANSPORTATION**
 - **FUEL CYCLE LIFE CYCLE STUDIES**
- **CAREFULLY DESIGNED MODELS CAN GREATLY REDUCE EXPERIMENTATION NEEDED**
- **M&S CAN BE USED TO HELP DESIGN EXPERIMENTS**

EFFECTS OF RADIATION

- **COMMON IN NUCLEAR INDUSTRY AND MEDICINE**
- **THREE COMMON TYPES OF RADIATION**
 - **PHOTON (X-RAY, GAMMA, UV, INFRA-RED)**
 - **ELECTRON**
 - **ALPHA PARTICLE**
- **BIOLOGICAL EFFECTS (HARMFUL AND BENEFICIAL)**
- **PROCESS REAGENT DAMAGE**
 - **ORGANIC (IX RESINS, EXTRACTANTS, PRECIPITANTS)**
 - **INORGANIC (CRYSTAL LATTICE DISRUPTION)**
- **PROCESS MATERIALS (INSULATION, METALS)**

SOME NUCLEAR NON- PROLIFERATION CONSIDERATIONS

- **MAJOR PROLIFERATION ACTIVITIES**
 - URANIUM ENRICHMENT
 - REPROCESSING FOR Pu RECOVERY
- **OVERT WEAPONS TECHNOLOGY DEVELOPMENT**
- **COVERT WEAPONS TECHNOLOGY DEVELOPMENT**
- **DETECTING CLANDESTINE FUEL CYCLE ACTIVITY**

TRANSPORTATION, STORAGE AND DISPOSAL OF NUCLEAR MATERIALS

- **NEW FUEL TRANSPORTATION**
- **USED/SPENT FUEL TRANSPORTATION**
- **USED/SPENT FUEL STORAGE**
 - **ON REACTOR SITES**
 - **IN WATER POOLS**
 - **IN CONCRETE STORAGE VAULTS**
 - **CENTRALIZED OFF-SITE STORAGE**
- **PERMANENT DISPOSAL**
 - **GEOLOGIC**
 - **ACTINIDE BURNING + GEOLOGIC DISPOSAL**

QUANTIFYING FUEL CYCLE RISKS

- **NUCLEAR RISK METHODOLOGY DEVELOPED FOR REACTOR RISKS**
- **NO COMPREHENSIVE APPLICATION TO THE FUEL CYCLE TO DATE**
- **PAST ACCIDENTS EMPHASIZE NEED FOR RISK ANALYSIS**
 - **THREE MILE ISLAND**
 - **CHERNOBYL**
 - **FUKUSHIMA DAI-ICHI**

ENVIRONMENTAL ASSESSMENT

- **A LEGAL REQUIREMENT FOR NUCLEAR FACILITIES**
- **EXAMINES A RANGE OF SCENARIOS**
- **RECOMMENDS A PATH FORWARD**
- **ASSESSMENT COVERS:**
 - **LAND USAGE**
 - **ANIMALS**
 - **PLANTS**
 - **HABITATION**
 - **WATER**
 - **TOXIC MATERIALS**

MIKE GREENBERG
