February 2005

Uranium Battery Update for KRCEE

Paul D. Dunbar, Ph.D., P.E.
Rhonda Lee-Desautels, Ph.D.

University of Kentucky
Paducah Extension Campus

Paducah Gaseous Diffusion

- 5 Billion Pounds of Depleted Uranium in Paducah
- $200M Conversion Plant Under Construction
  - Convert UF_6 to U_3O_8
- Low Radiation Levels for depleted uranium 0.1% U_{235} compared to 0.7% U_{235} for natural uranium
  - Great source for U_3O_8

Collaborators, Consultants, and Technicians

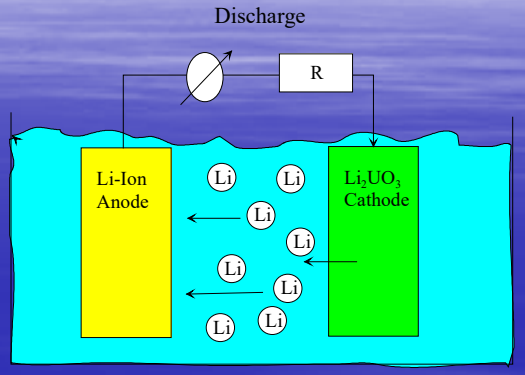
- Applied Power International (Idaho, California)
  - Walter Tracinski, Lithium Battery Expert
- Center for Applied Energy Research UK
  - Dr. Stephen Lipka-Electrochemist/Material Scientist
- Dr. Richard Howard
  - Inorganic Chemist--Battery Materials Consultant (25 years experience in Industry)
- Kristin Banik – Technician Undergraduate in Materials Science

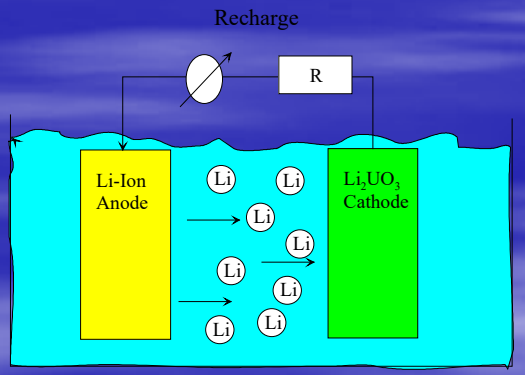
Project Goals

- Characterize uranium dioxide and lithiated uranium dioxide's electrochemical properties in various organic solvents/lithium salts
  - Purchased Hohsen Cell
- Test the cells using common electrochemical methods to determine the reversibility of Uranium compounds
  - cyclic voltammetry
  - impedance spectroscopy
- Information will be used to construct a battery with uranium dioxide as the cathode.
- Manufacturing of uranium-lithium compounds in a furnace to mirror the construction of manganese-lithium compounds commonly used in commercial batteries.
  - **Lithiated Uranium Oxides will allow for lithium intercalation**
  - **Based on theory Li_2UO_3 is the best candidate**

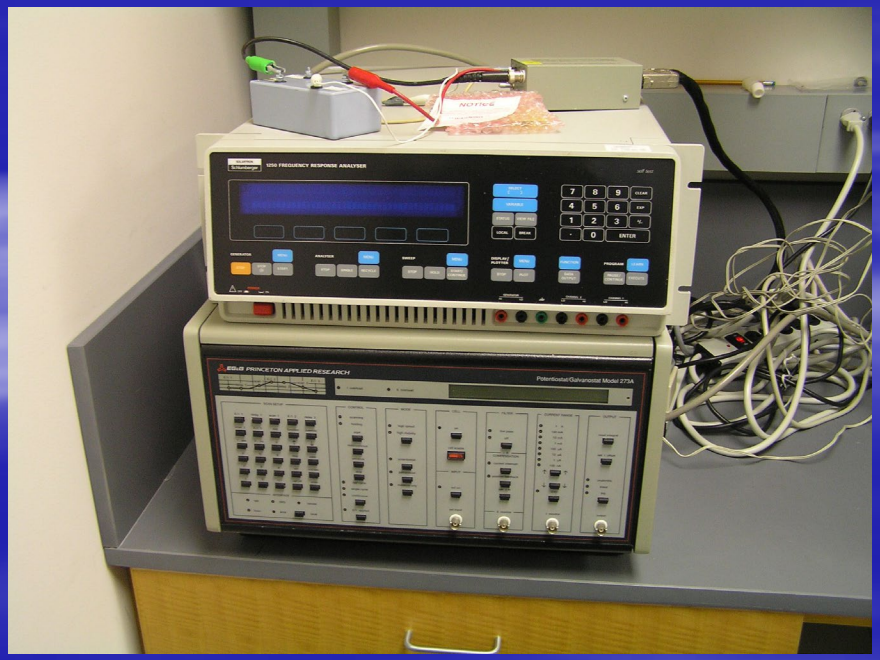
Characterization

- Lithiated Uranium Dioxide should produce the best cathode material—better than UO_2





ReCharge and Discharge of Lithium-Ion Anode and Lithiated Uranium dioxide Cathode Battery

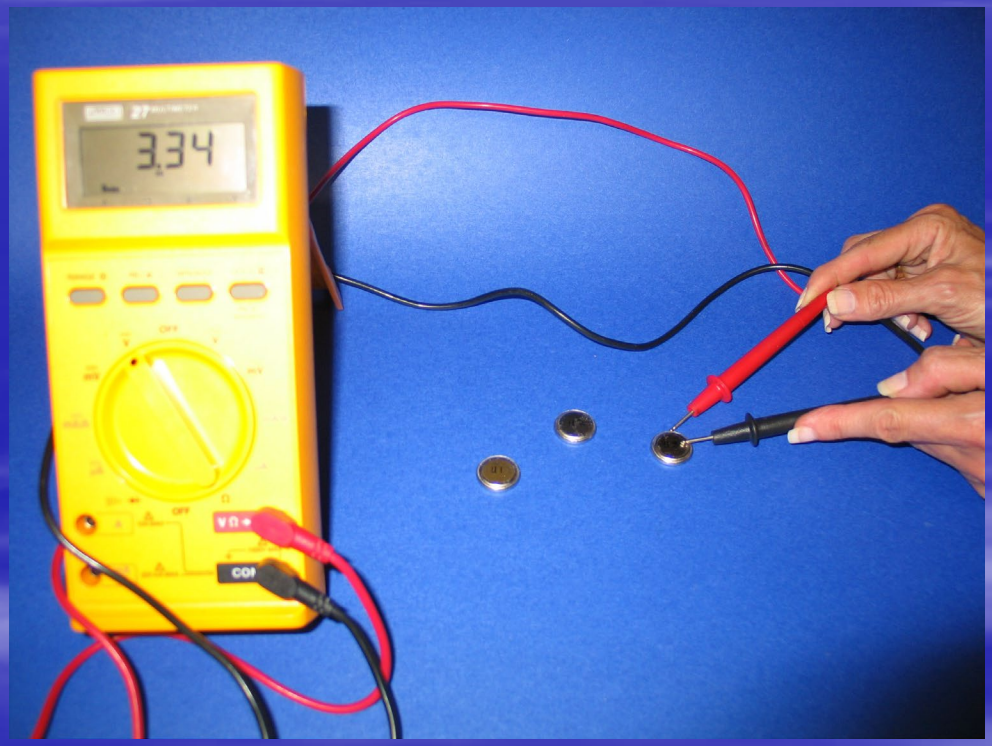


Project Status

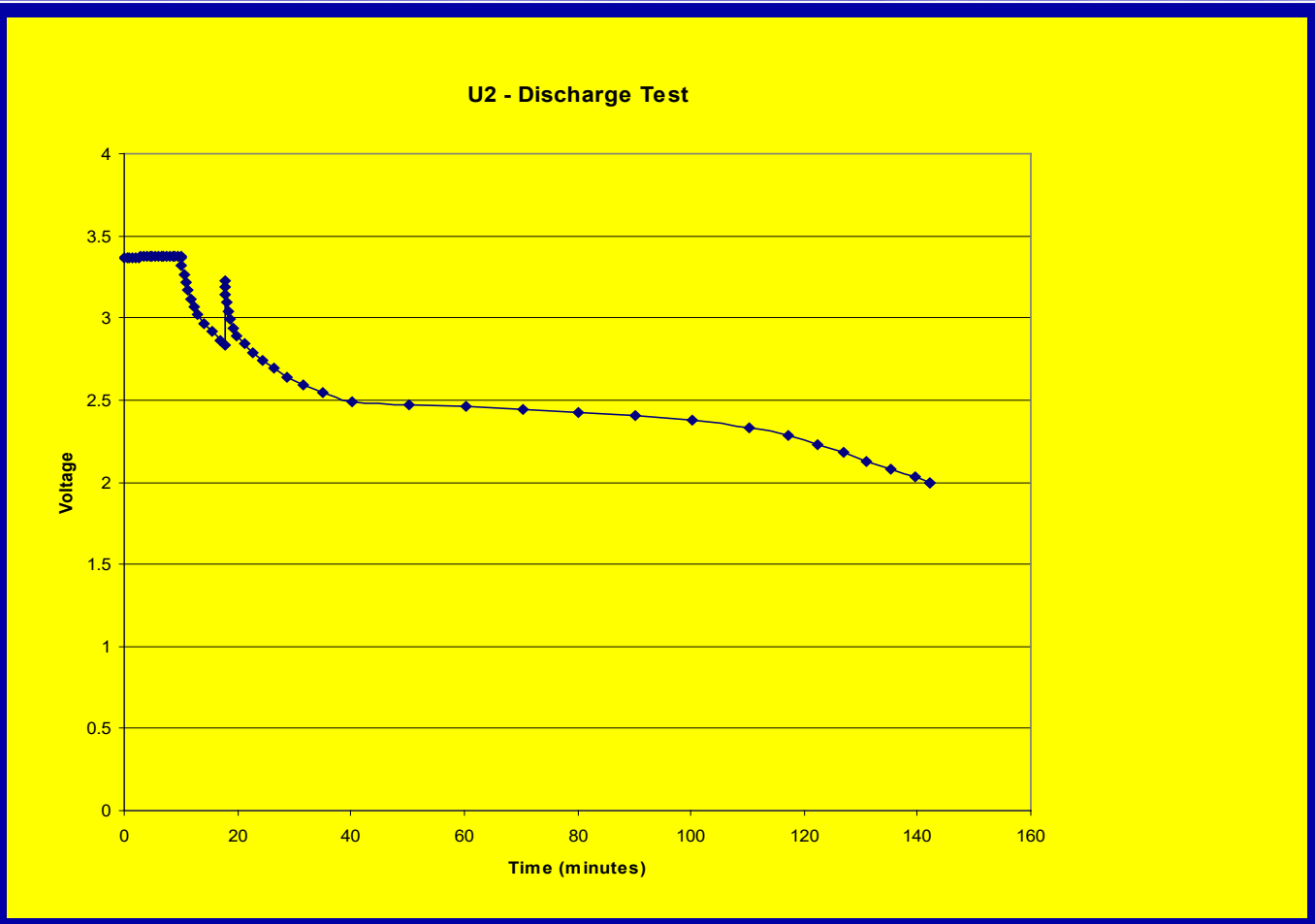
- Prototype Li-UO_2 battery constructed (Old News)
- lithiated UO_2 and U_3O_8 in a muffle furnace form $Li_xU_yO_z$ (Old news)
  - Waiting for Analysis Results from CAER (Depressing News)
  - Switched to Geological Survey and hired student (I hope is good news)
- Constructed 5 new E-cells to make 6 total cells for data quality comparison of different materials (Interesting news)
- Implementing Dr. Howard's recommendations (In Progress)
  - Tube furnace to create reducing atmosphere to create Li_2UO_3
  - SS330 crucibles
- March through July should be a product time

Lithium-Uranium Battery Construction

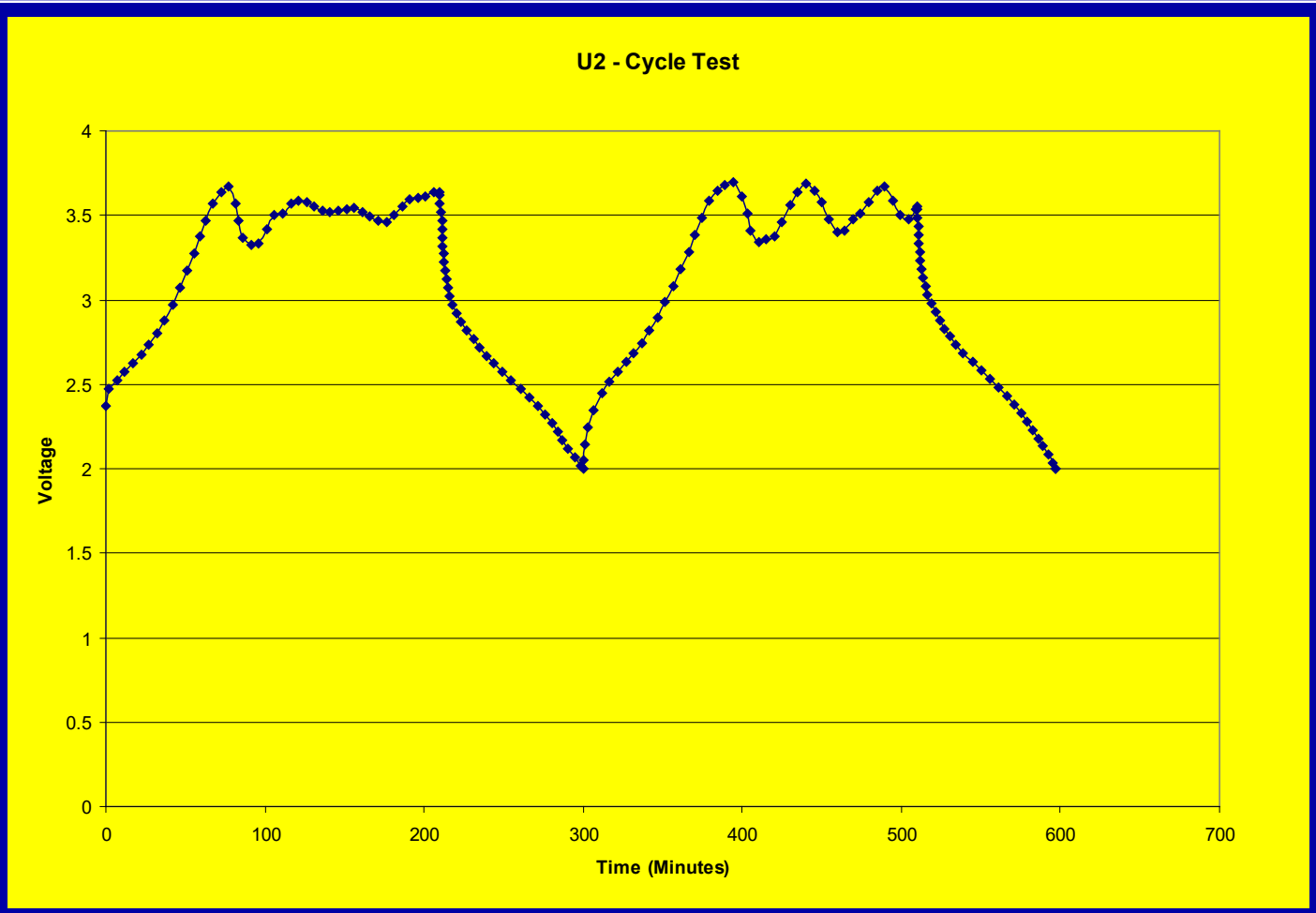
- Baseline Battery
- Materials
  - 1.000 g of UO_2
  - 0.200 g of carbon
  - 0.100 g of TFE
  - ~1 ml of solvent was added
- Maccor Battery Testing equipment
- Battery Press
- Lithium anode
- Separator
- Uranium Dioxide Cathode



Li-UO_2 discharge curve



Li-UO_2 Recycling Curve



Consultant Recommendations

- Purchase Ball Mill to grind powders to 50 microns particle size
- Use Lithium Hydroxide as reactants instead of lithium carbonates
- Use SS330 reaction vessels (Specially made at a Machine shop)
- Change to a Tube Furnace to create reducing conditions

Lithiated Metal Oxides

- Lithium Metal Oxides used in Batteries
  - $LiNiO_2$, $LiMn_2O_4$, and $LiCoO_2$
- Cathode material used in advanced rechargeable batteries
  - $LiMn_2O_4$
- Goal is to make Lithium Uranium Spinel for advanced rechargeable batteries
  - $Li_xU_yO_z$

Muffle Furnace

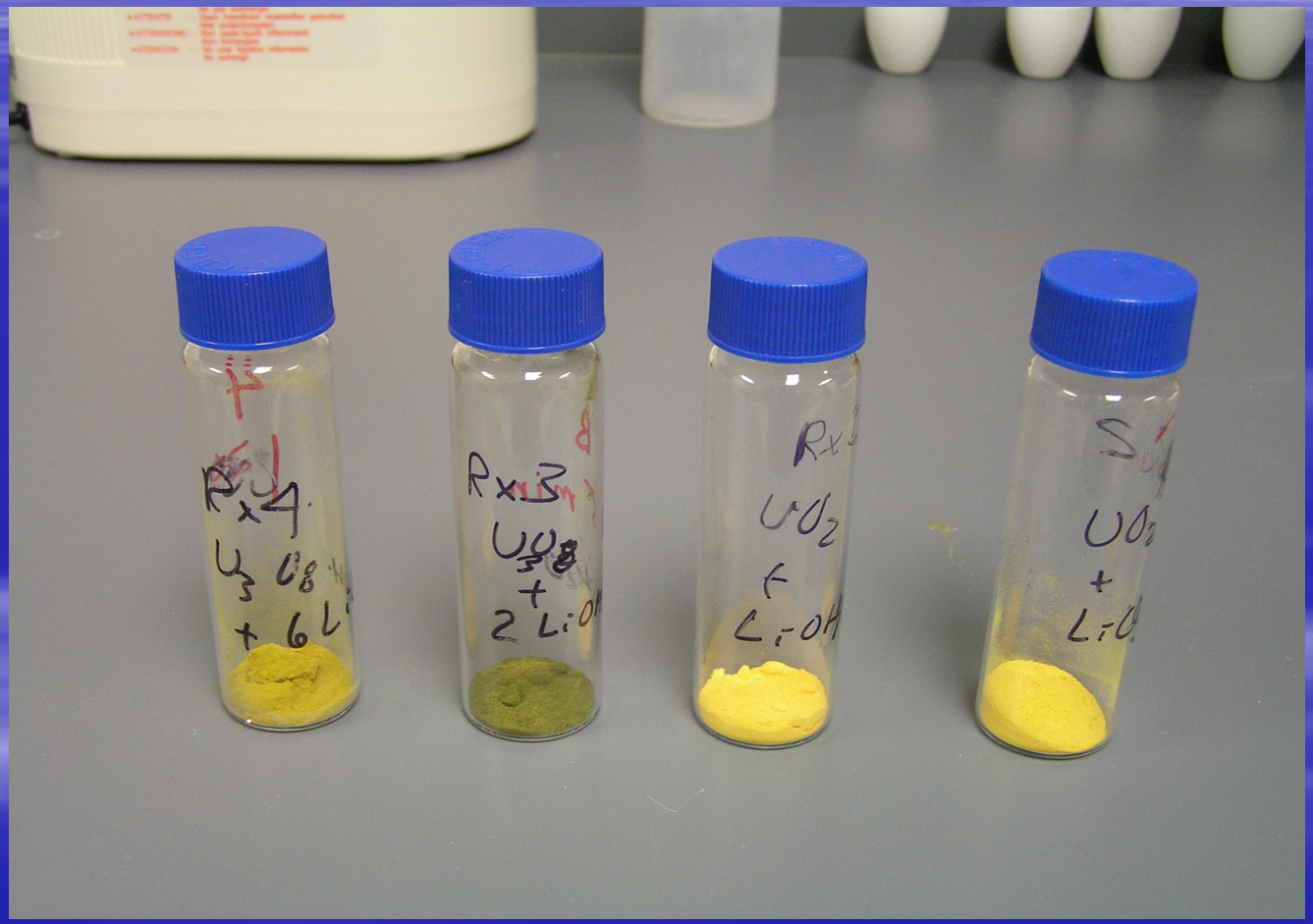
Lithiated Uranium Dioxides

- Chemical Reactions in Muffle Furnace
- The reactants $Li(OH)_2$ or $LiCO_3$ decompose to Li_2O
  - $Li_2O + UO_2 \rightarrow Li_2UO_3$
  - $U_3O_8 + Li_2O \rightarrow Li_2U_3O_9$
  - $U_3O_8 + 2Li_2O \rightarrow Li_4U_3O_{10}$
  - $U_3O_8 + 3Li_2O \rightarrow Li_6U_3O_{11}$

Recipe

- Step 1: Heat to 450 C at 2 C/min
- Step 2: Soak at 450 C for 1 hour
- Step 3: Ramp to 650 C at 2 C/min
- Step 4: Soak at 650 C for 3 hours
- Step 5: Turn oven off and allow to cool overnight.

Some Reactions

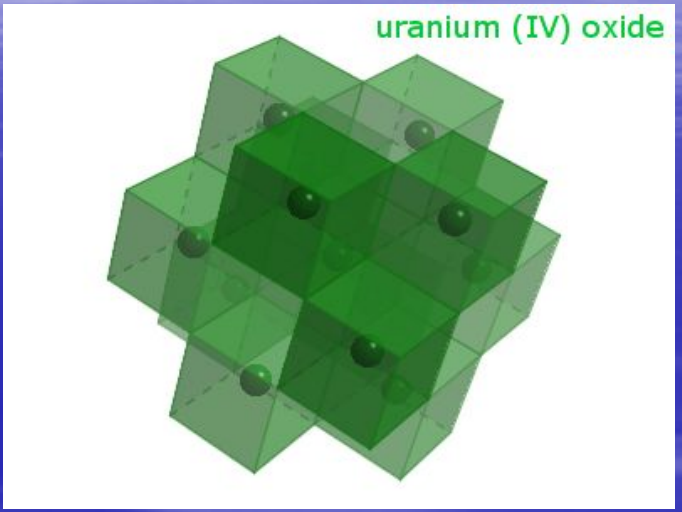


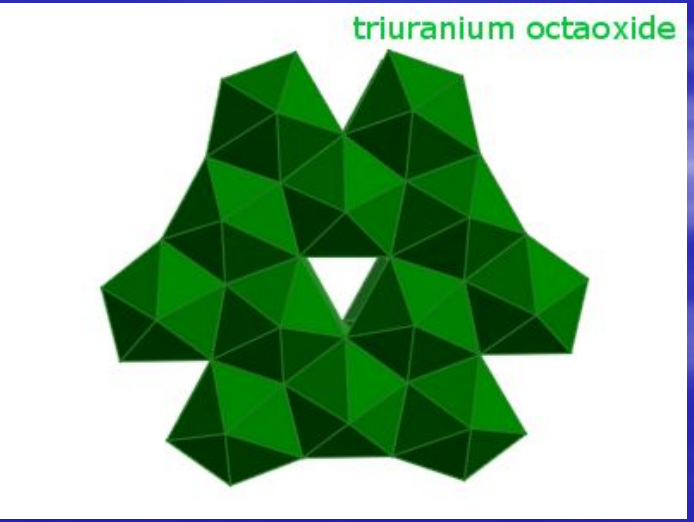
Lithiated Compounds

- Make Li_2UO_3 with a $^{+}4$ Valence
  - Based on Phase Diagrams and the Literature
- Tube Furnace is required to create a reducing atmosphere
  - 5% Hydrogen 95% Argon in a tube furnace
  - U_3O_8 + Li(OH)*H2O $\longrightarrow$ Li_2UO_3

Analysis of Products

- Structure and Composition
  - X-Ray Diffraction
  - X-Ray Fluorescence
- Electrochemical Behavior
  - Cyclic Voltammetry
  - Impedance Spectroscopy

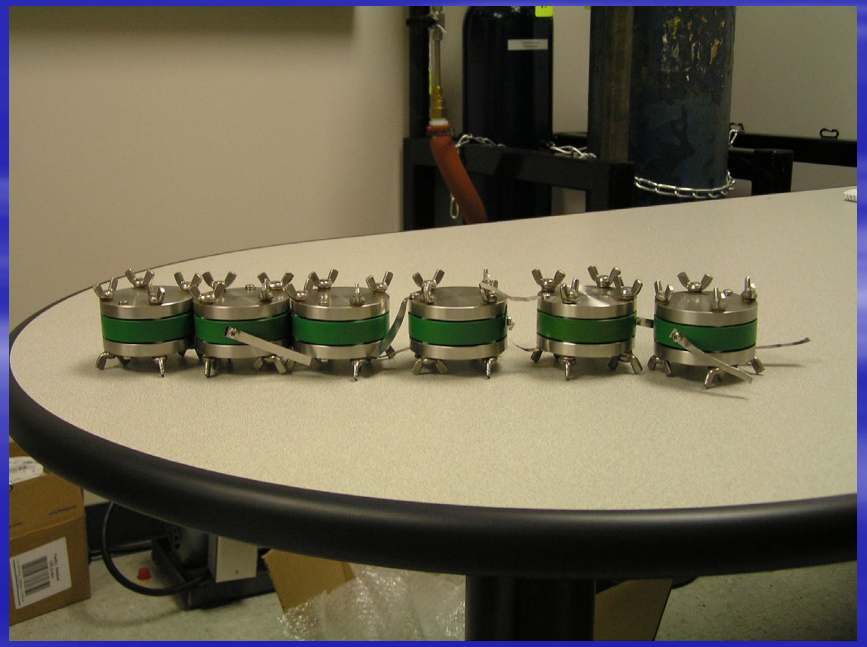




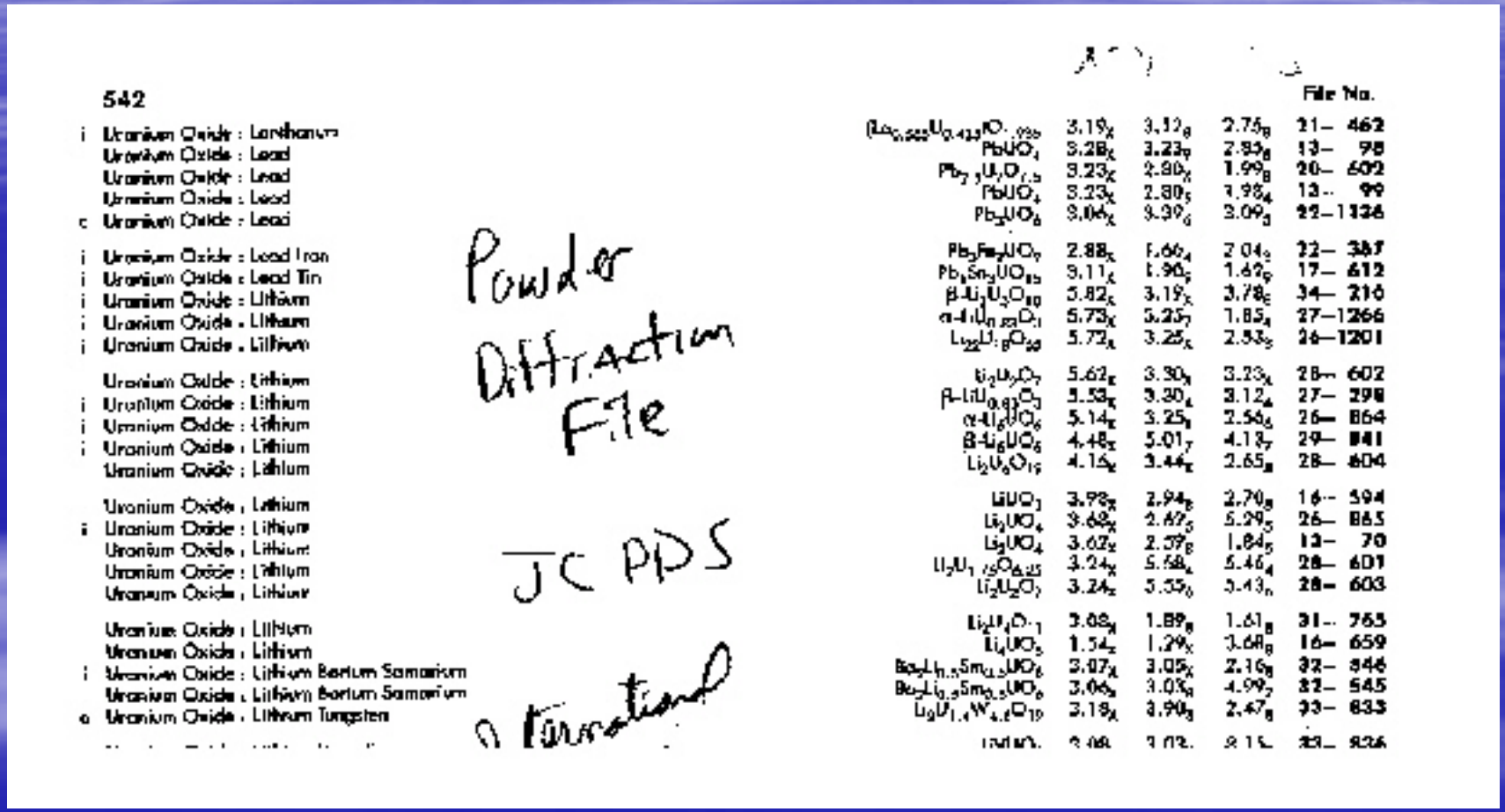
Battery Conclusions

- Prototype UO_2 battery results show a stable open circuit potential and the ability to be a recharged. This is a baseline system.
  - The prototype battery results indicate there is a need to optimize the UO_2 material in terms of particle size to improve results.
- Lithiated UO_2 or U_3O_8 are better candidates for cathode battery materials.
  - Some of these compounds have been constructed and they are being analyzed for structure and composition

E-cells



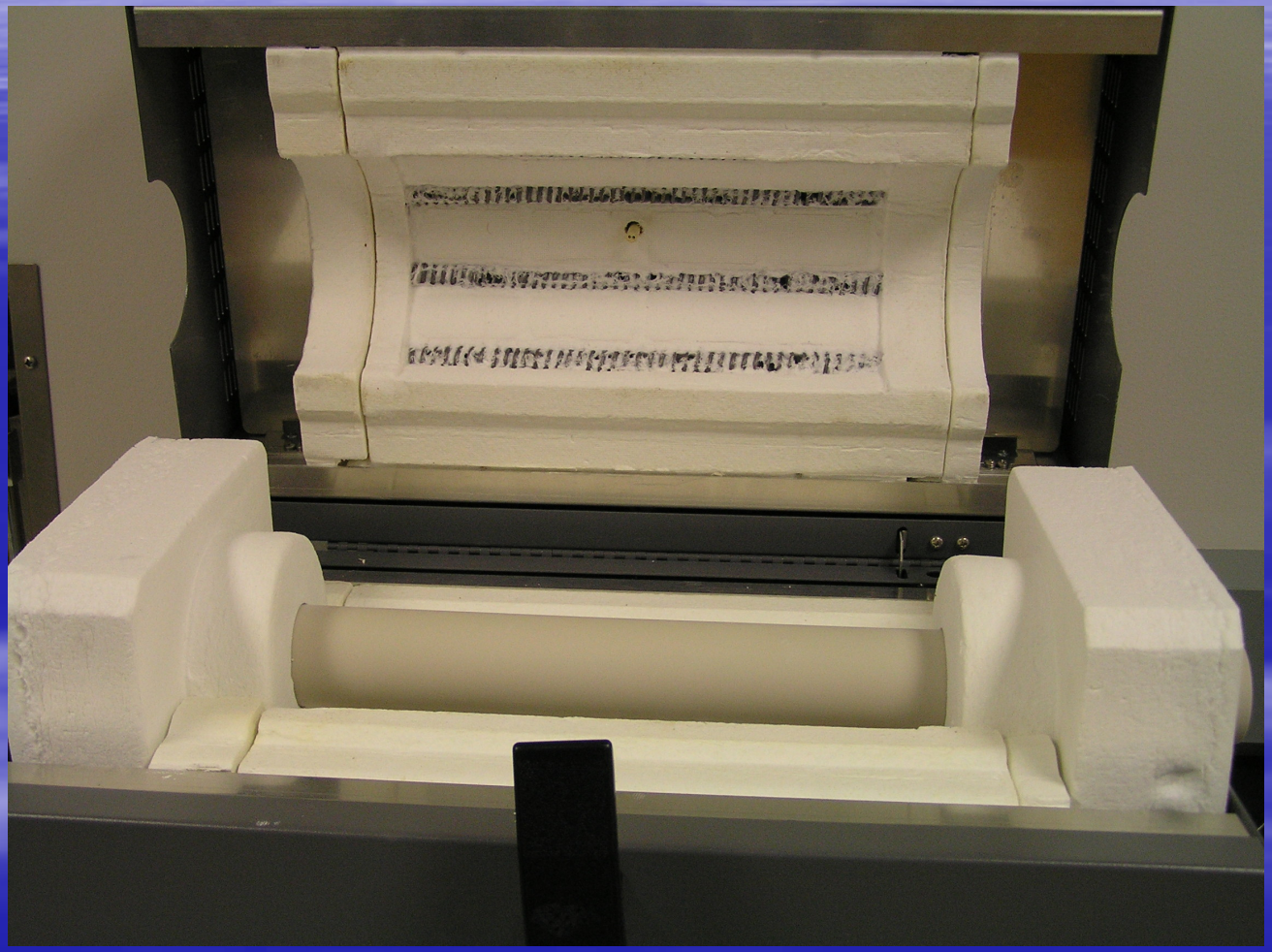
X-ray library



Tube Furnace and X-ray Work

- Tube Furnace $3300
  - Process tube
  - Electrician and $1000 to wire it up
- X-ray work
  - CAER
  - Undergraduate assistant to do x-ray analysis

Tube Furnace



Progress Summary

- Purchased tube furnace 1st week of January
- SS330 crucibles constructed
- Multiple e-cells constructed
- Tube Furnace working 2nd week of February
  - Waiting for electrician ($1000)
- Hired Undergraduate in Materials to run Before and after sample for electrochemical analysis
  - Geological Survey
- X-ray sample holders under construction