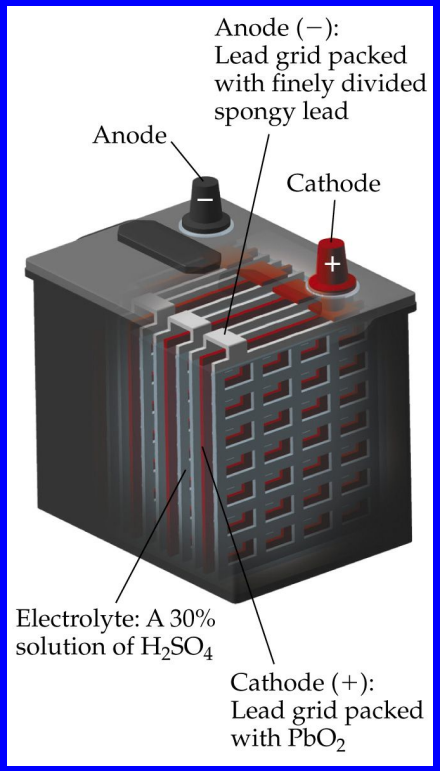

May 2006

Uranium Battery Update for KRCEE

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Applied Power International

University of Kentucky
Paducah Extension Campus

Paducah Gaseous Diffusion

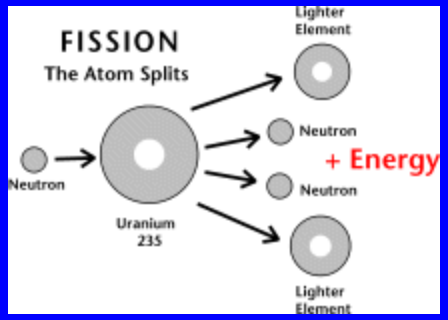
- 5 Billion Pounds of Depleted Uranium in Paducah
- $200M Conversion Plant Under Construction
  - Convert UF_6 to U_3O_8
- Low Radiation Levels for depleted uranium 0.1% U_{235} compared to 0.7% U_{235} for natural uranium
  - Great source for U_3O_8

Uranium Properties on Paper

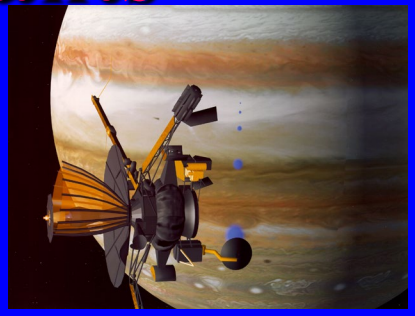
- **Uranium Standard Reduction Potential Voltage of 4.7 Volts per Cell from U to $UO_2(OH)_2$ (in alkaline environment)**
- **Lithium is 3V per cell**
- **Lead is 2V per cell**
- **U can supply 6 electrons instead of 2**
  - **In reality it is less than 3 electrons**
- **Uranium is a Highly reactive material**

Potential for compact battery
With a high power density

$$UO_2(OH)_2 \xleftarrow{-0.3V} UO_2 \xleftarrow{-2.6V} U(OH)_3 \xleftarrow{-2.10V} U$$



Collaborators and Consultants

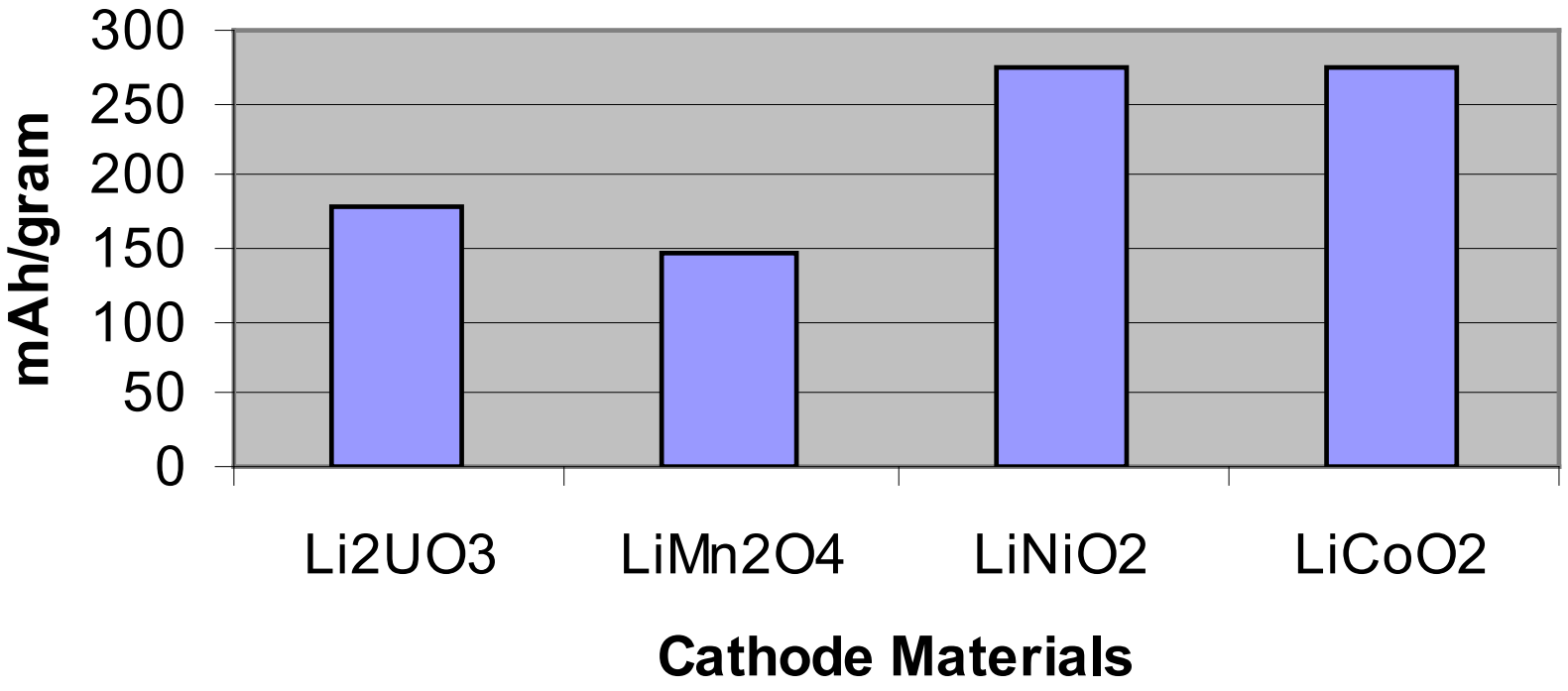


- Walter Tracinski
  - Applied Power International (Idaho) Lithium Battery Expert
  - B.S. Chemistry RPI
  - Consultant to US Navy, US Air Force, and The Boeing Company. Contracts for batteries on F-18s and F-16s.
  - Tested the Galileo spacecraft batteries (500,000 cycles to pass the recharge/discharge)
- Dr. Stephen Lipka
  - Center for Applied Energy Research UK -Electrochemist/Material Scientist,
- Dr. Richard Howard
  - Inorganic Chemist--Battery Materials Consultant (25 years experience in Industry) Developed Cathode materials for Kerr-McGee
- Dr. Chris Johnson
  - Dr. Daniel Thomas, Electrochemical Engineer, The Boeing Company
  - Internal Battery Consultant, The Boeing Company
- Dr. Joseph Spruell
  - Professor of Materials Science, The University of Tennessee

Technical Project Goals

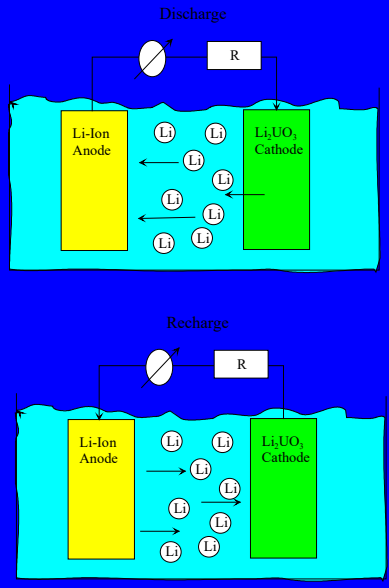
- Mirror the development of manganese dioxide and lithiated manganese oxides as battery materials
  - Characterize uranium dioxide and lithiated uranium oxide's electrochemical properties in various commercial organic solvents/lithium salts
  - Build cells and test using common electrochemical methods
    - cyclic voltammetry
    - impedance spectroscopy
  - Use this information to construct a battery
    - Lithiated Uranium Oxides will allow for lithium intercalation
    - Based on theory Li_2UO_3 is the best candidate

Theoritical Capacity of Cathode Materials in Lithium Ion batteries

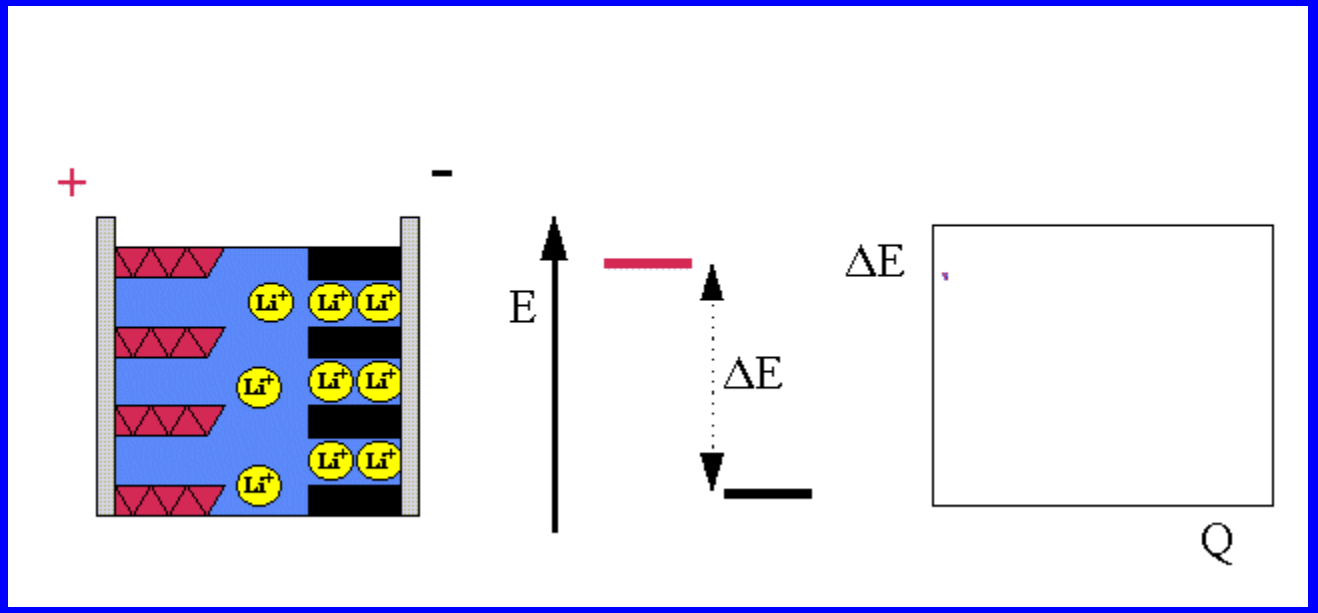


Battery limited by the rate at which the cathode can receive the electrons From the anode.

Animation of Lithium-Ion Cell



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



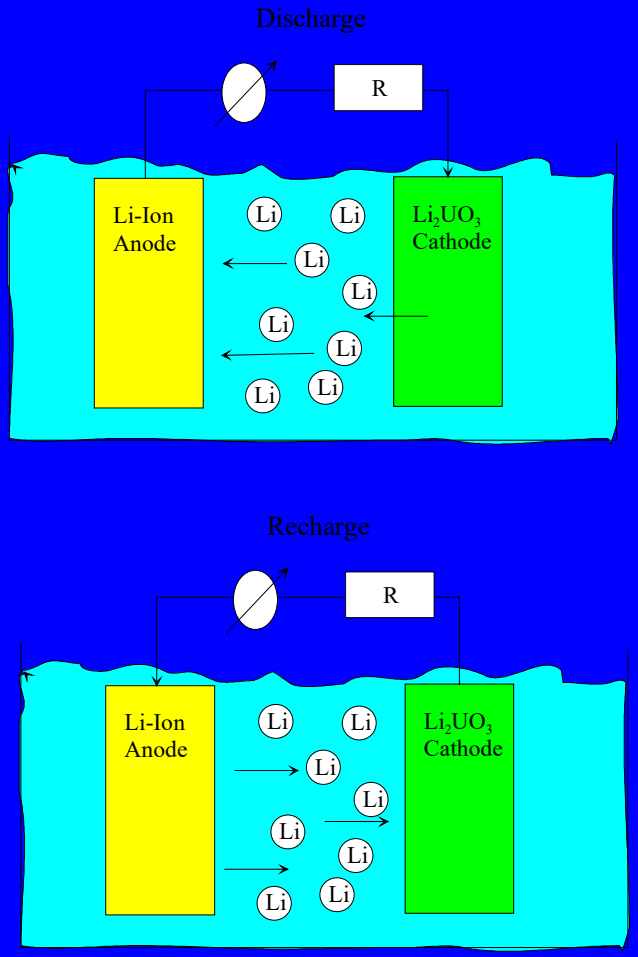
Cathodes must have crystal structure to allow re-intercalation

Hybrid Batteries

- Currently hybrids use Nickel Metal Hydride batteries 330 cells
  - Current development Lithium-Ion batteries
  - Toyota has a working minivan prototype in Tokyo using lithium-ion with Lithiated metal phosphate as the cathode in the batteries

Current Work

- Optimize Lithiated Material as Cathode
  - Intercalation Behavior
- UO_2 as Capacitor
  - Planned experiments to make exact charge storage capacity



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

Load leveling battery

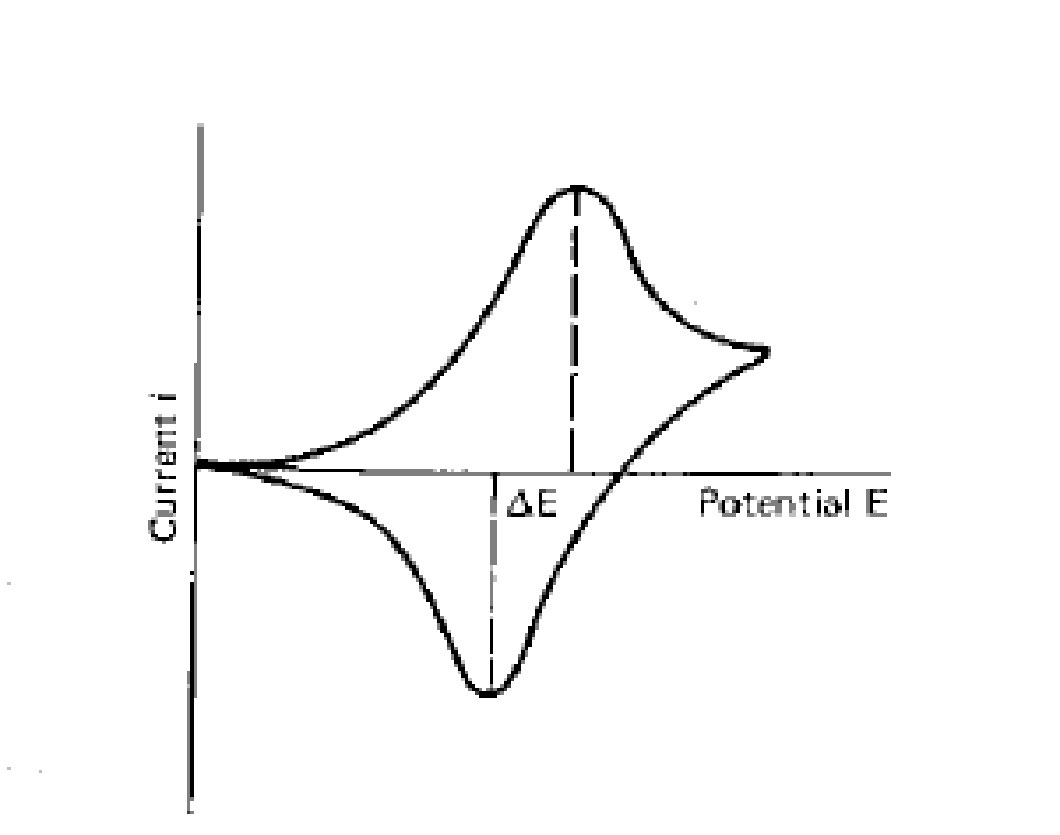
- $10 Billion a year business
- Potential Markets
  - Energy Storage, Load Leveling, and Thermal batteries, Military Applications (Radar stations etc.)
- Secondary Battery
  - Rechargeable
  - High power density
  - Good performance at desired temperature
- Currently lead acid is used as load leveling (Pb/PbO2 in H_2SO_4)
- Japanese are working on lithium-ion load leveling batteries
  - Combining large number of cells

http://www.sei.co.jp/sn/2001/09/6b.html

Lithiated Uranium Oxide Material

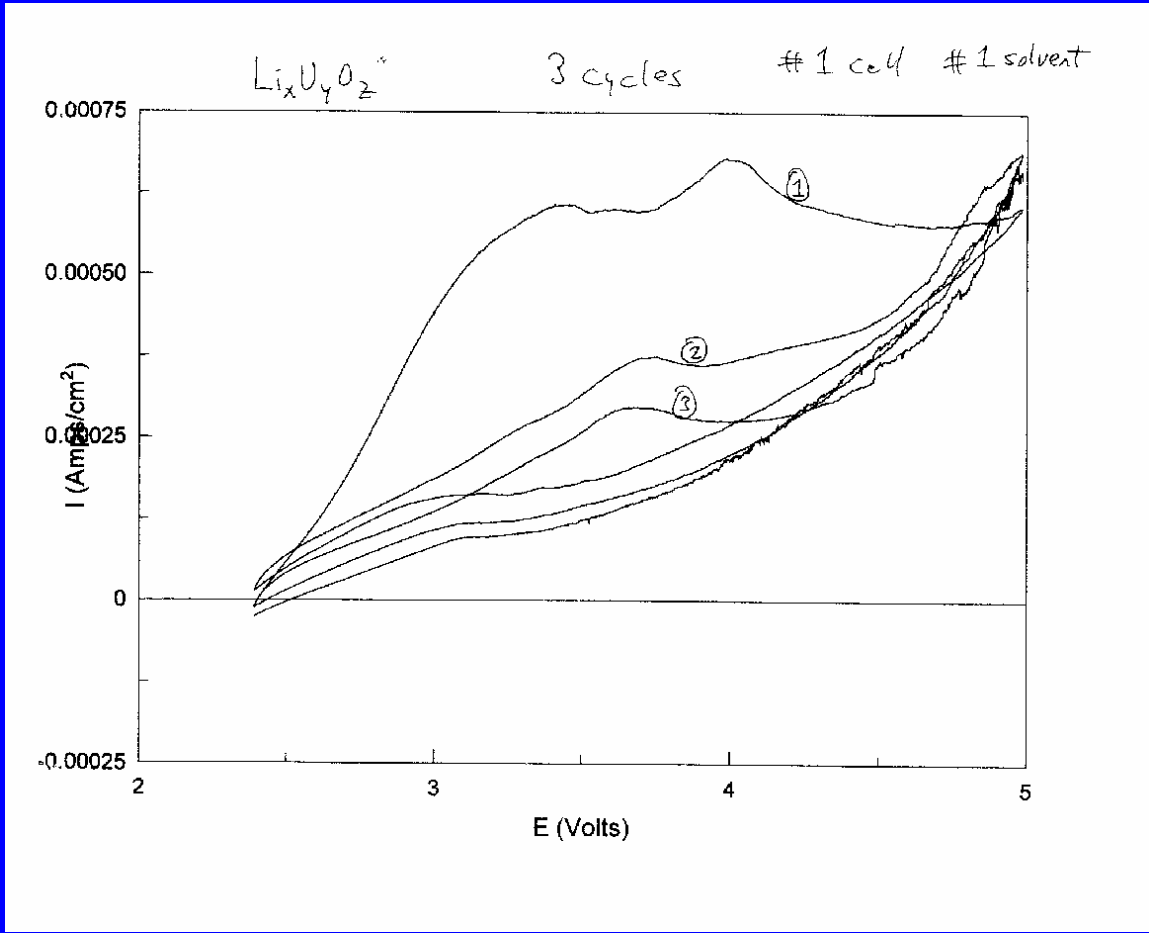
- Load Leveling Battery
  - 2,000 Amp-hours with 24.5 lbs
  - 15,000 Amp-hours with 183.75 lbs
- Southern California Edison has a load leveling battery with 8256 cells with each of 3250 Amp-hours
  - 164 tons of uranium materials
- 10 Billion pounds could produce 50 million batteries at 200 pounds a piece

Textbook CV of reversible, diffusion controlled process

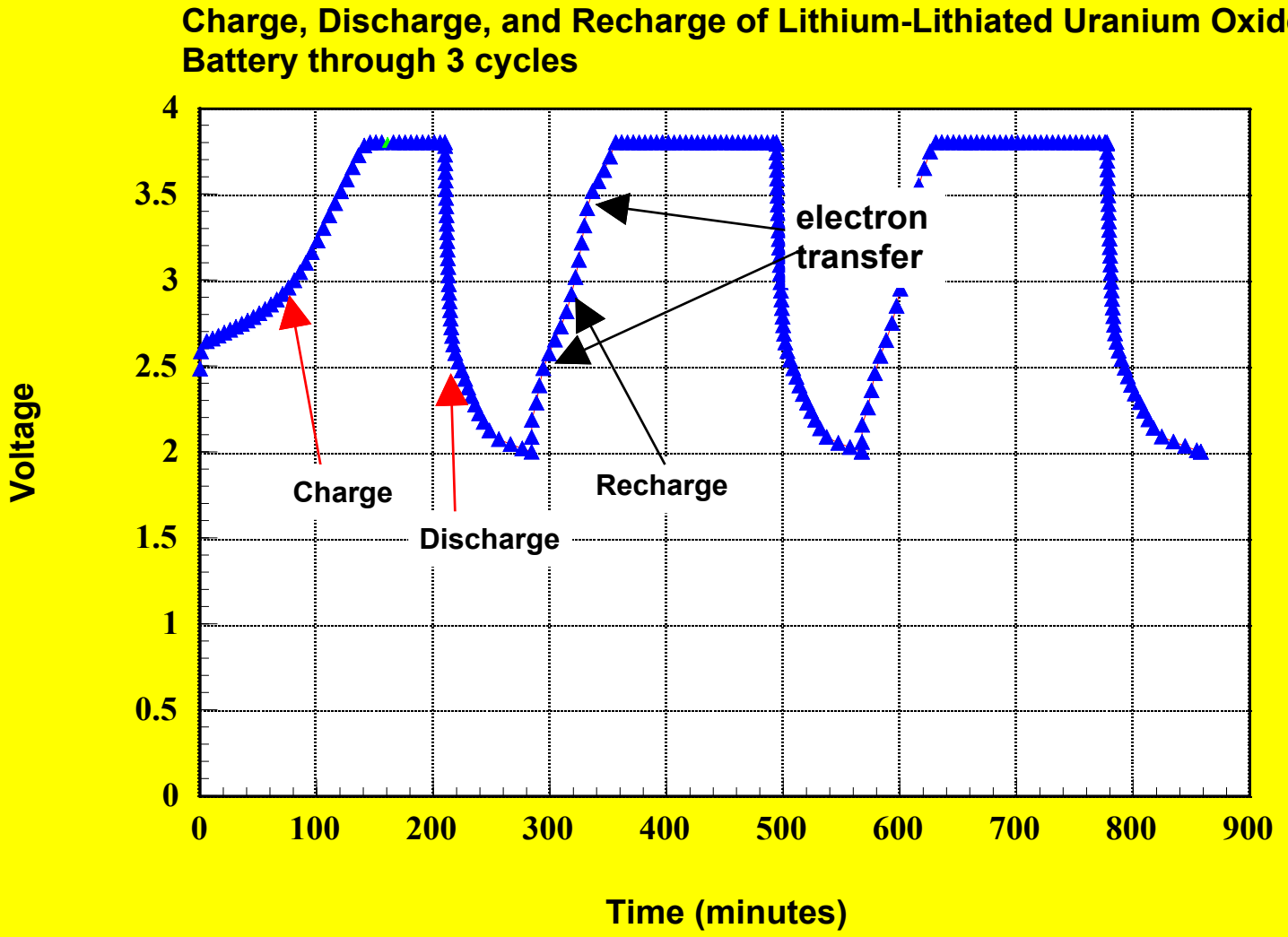


CV of our Material

- 12 times the current as seen in UO_2 alone.
- Lithium is in the structure, but no intercalation is seen.
- Membranes in cell created a very high resistance due to multi-layer structure

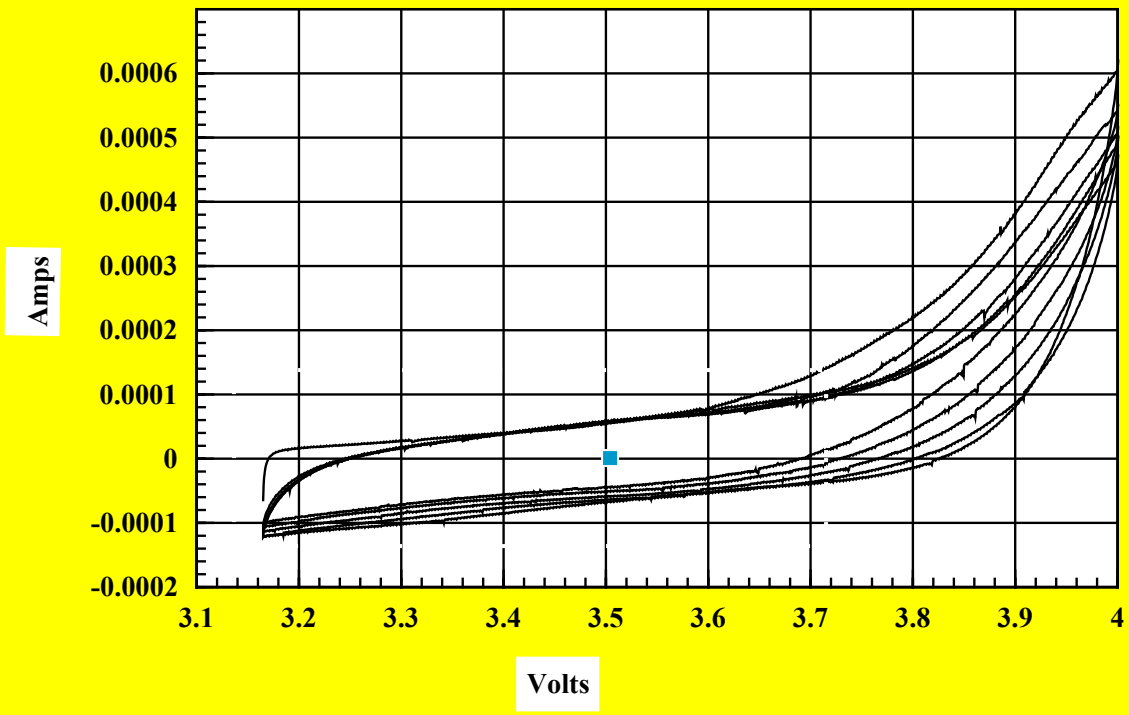


Lithium/Lithium uranium battery



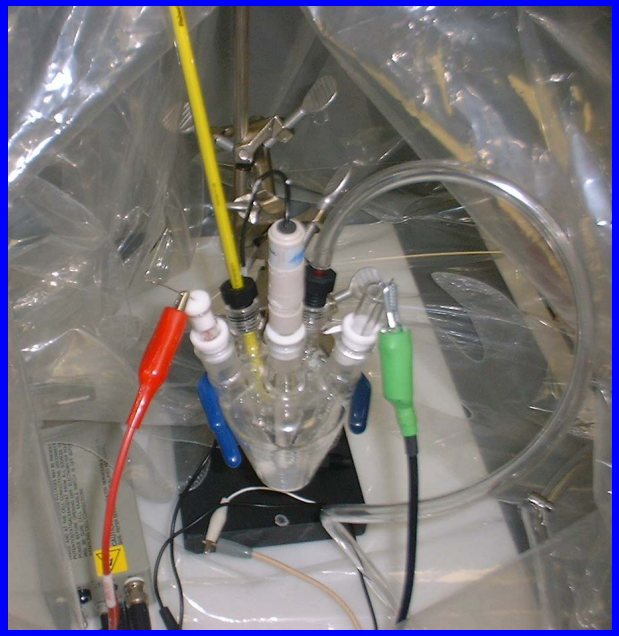
CV of UO2—Capacitor Material

Figure 4. Cyclic of UO2 in 1 M Tetrafluoroborate

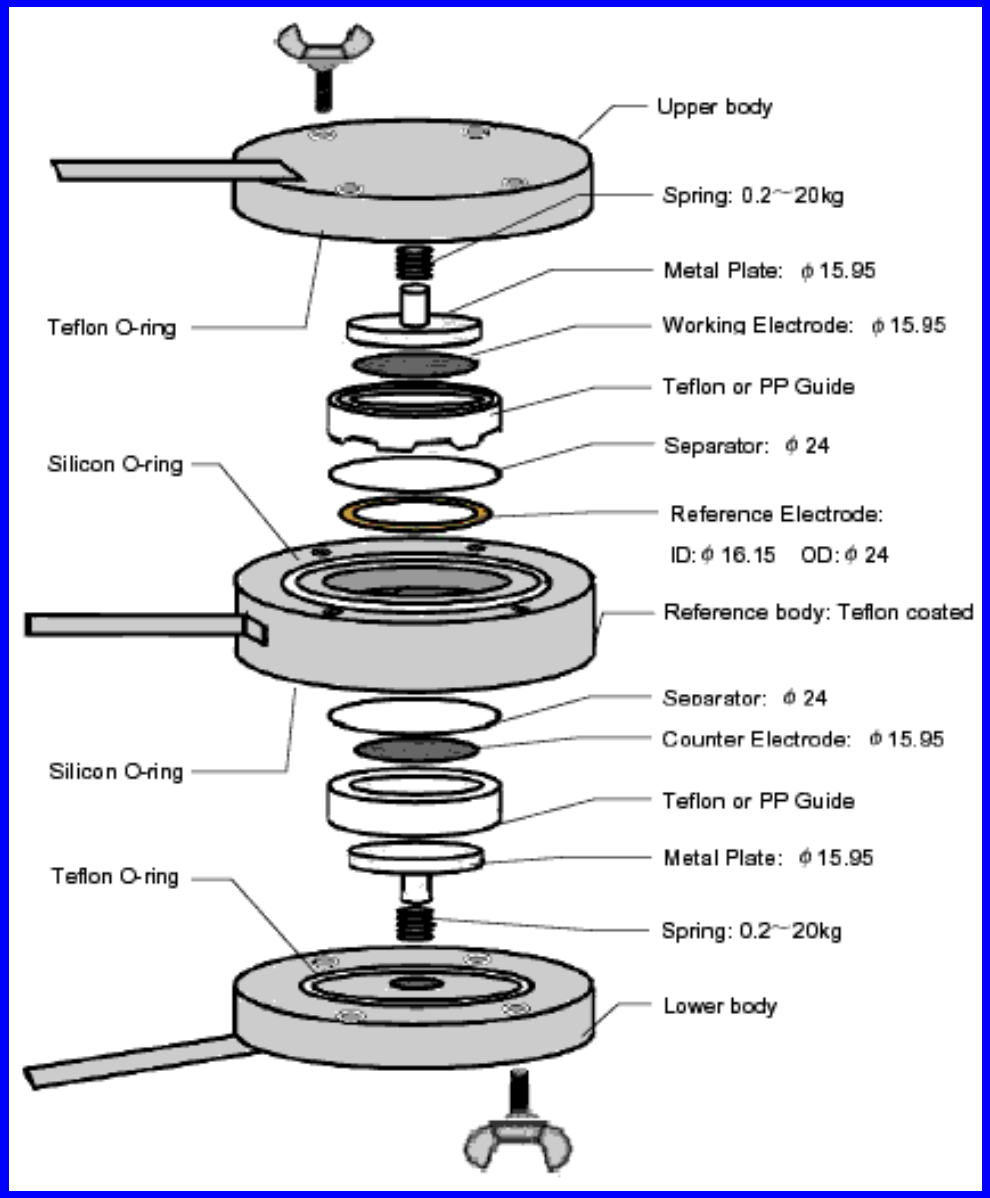


Characterization

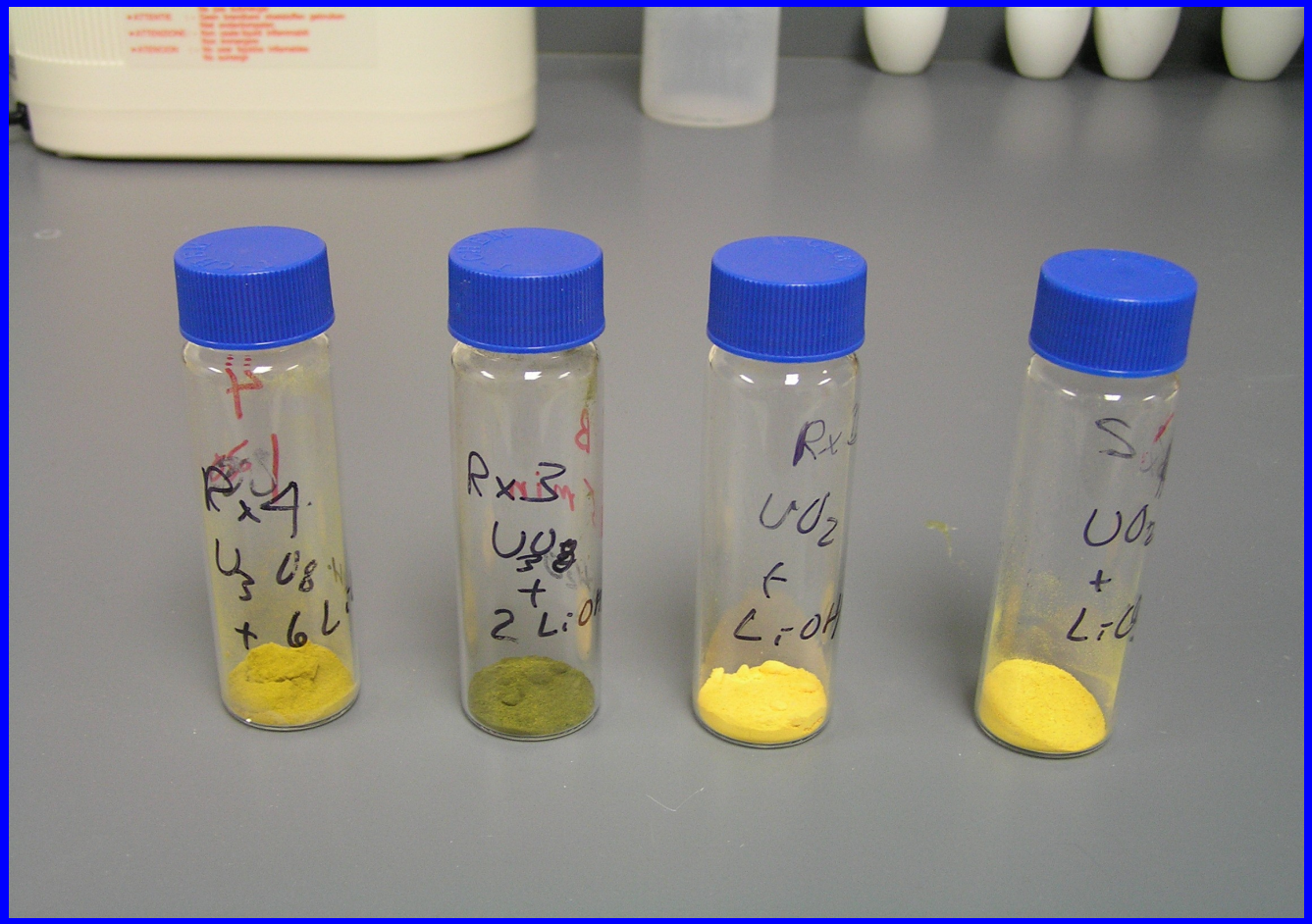
- Cells



Internal Parts of E-Cell



Some Reactions

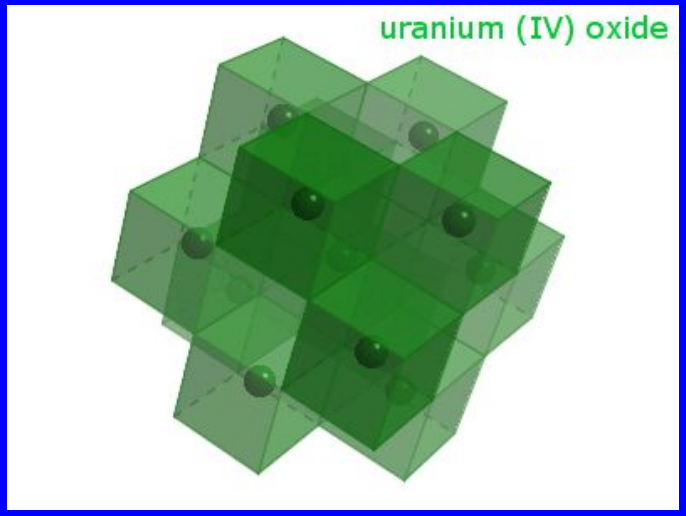


Lithiated Compounds

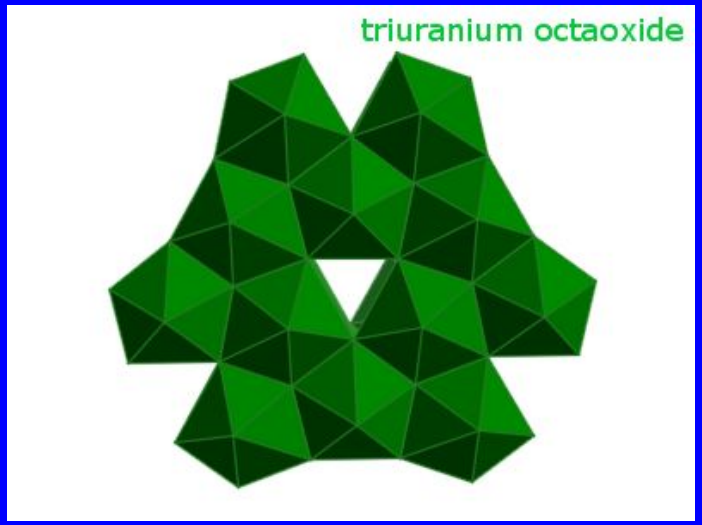
- Make Li_2UO_3 with a $^{+}4$ Valence
  - Based on Phase Diagrams and the Literature
- Tube Furnace is required to create a reducing atmosphere
  - 5% Hydrogen 95% Argon in a tube furnace
  - U_3O_8 + Li(OH)*H2O $\longrightarrow$ Li_2UO_3

Analysis of Products

- Structure and Composition
  - X-Ray Diffraction
  - X-Ray Fluorescence



- Electrochemical Behavior
  - Cyclic Voltammetry
  - Impedance Spectroscopy

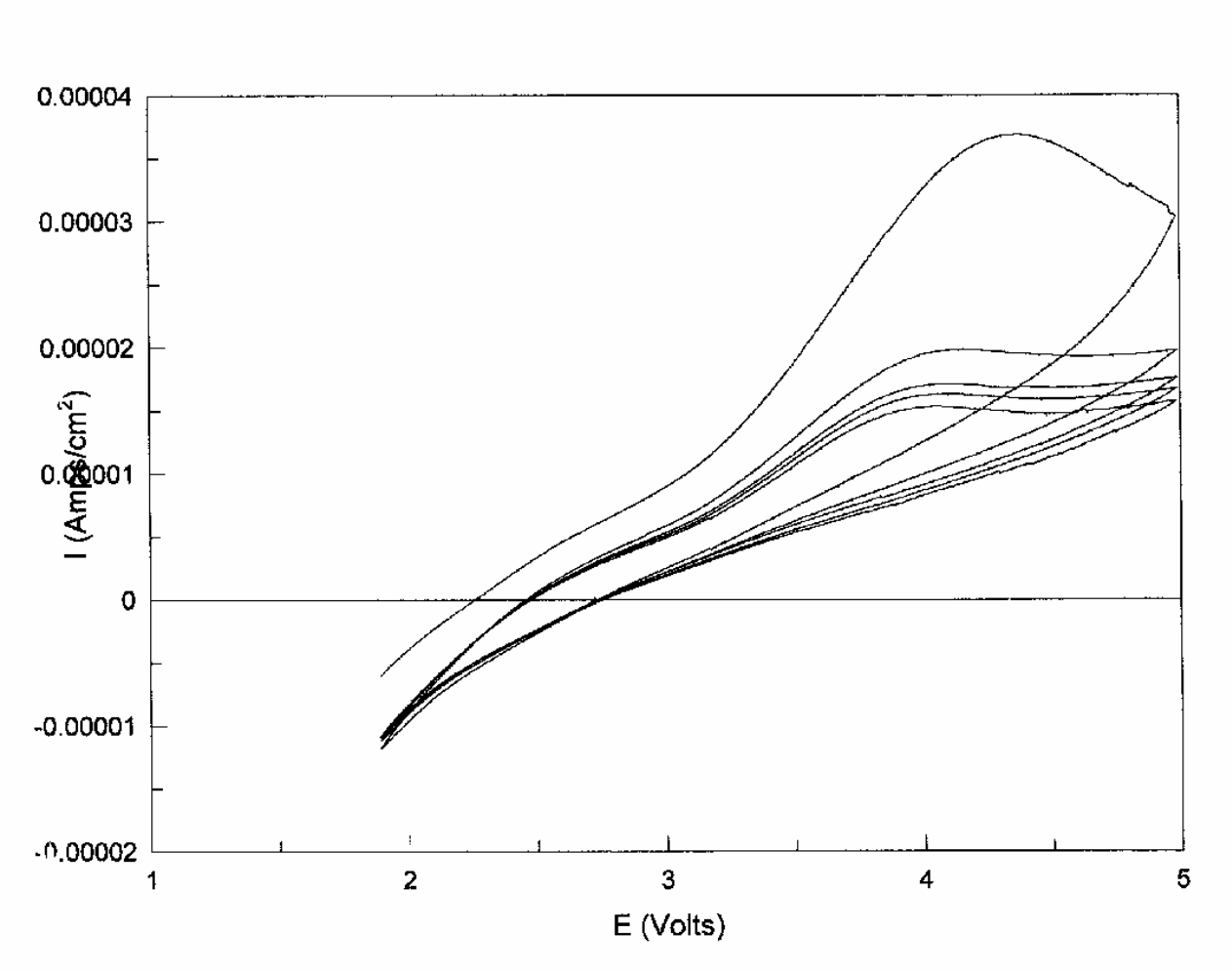


Cyclic Voltammetry Experiments

- Technique used for determine formal potential for a half reaction.
- Looking for redox potentials of electroactive species
- Linear potential sweep of working electrode with measurement of current.
- Plot of current vs. potential is cyclic voltammogram.

CV of UO_2 Electrode

(Lithium metal RE, Lithium metal CE
UO2 WE, 1 M Lithium Tetrafluorborate in 1:2 PC/DMC)



Literature CVs of Lithiated Metal Oxides – Rao, et. al.

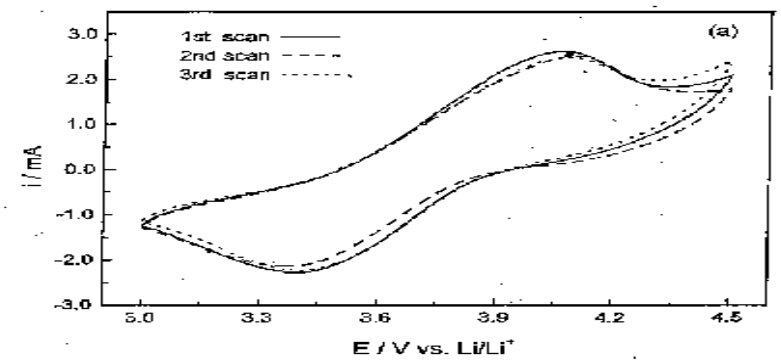


Fig. 3 Cyclic voltammograms of the $Li_{0.88}Ni_{1.12}O_2$ electrode at scan rates of **a** 0.1 mV s^{-1} and **b** 0.01 mV s^{-1}, with 1 M $LiClO_4$ in PC as the electrolyte

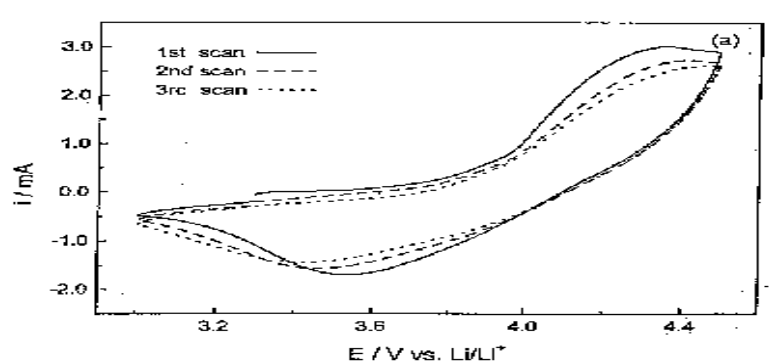
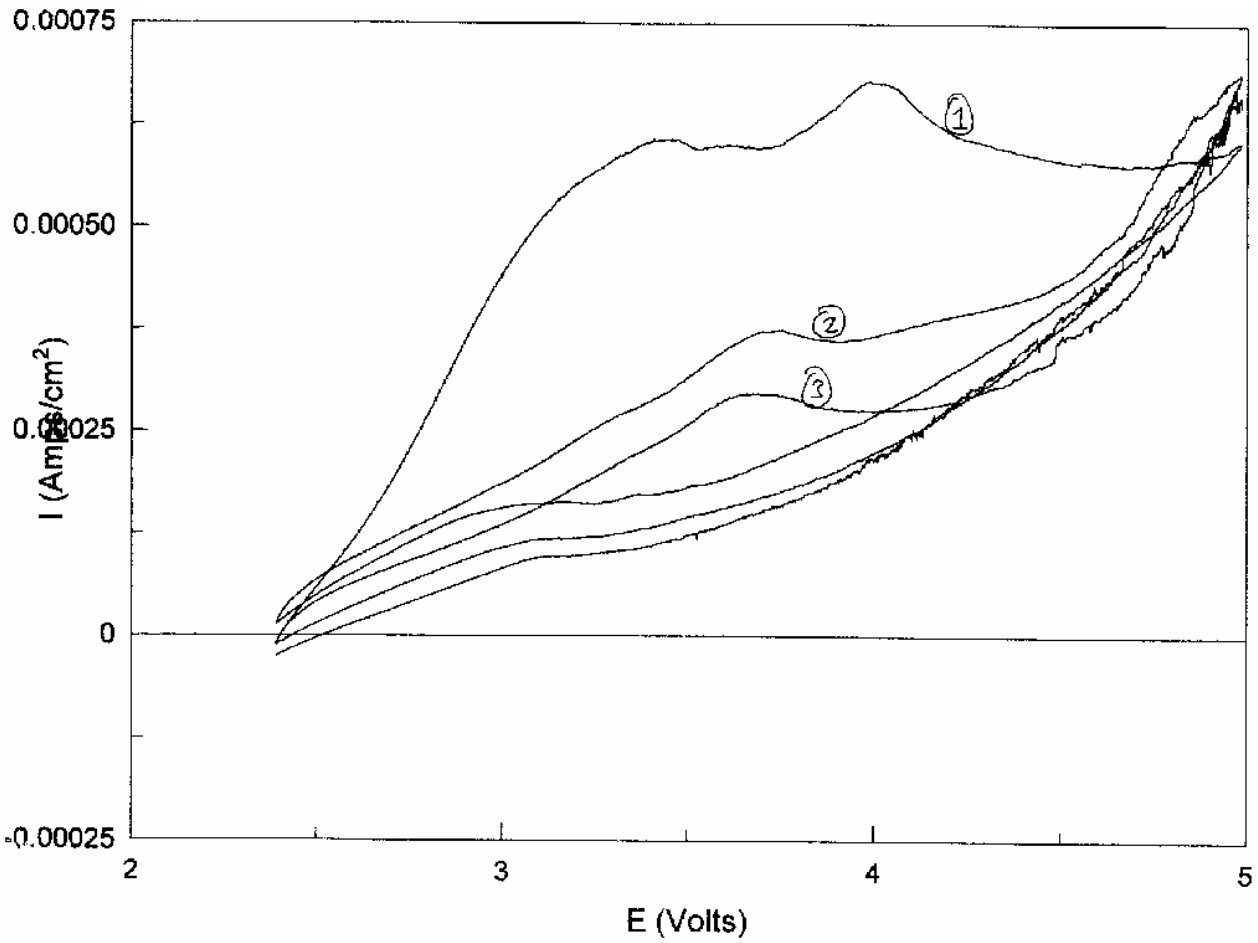


Fig. 4 Cyclic voltammograms of the $LiCoO_2$ electrode at scan rates of **a** 0.1 mV s^{-1} and **b** 0.01 mV s^{-1}, with 1 M $LiClO_4$ in PC as the electrolyte

CV of $Li_xU_yO_z$ Electrode



Summary

- Formulated new lithiated uranium compound $Li_xU_yO_z$ that has more than 10 times the current output of uranium dioxide by itself.
  - Lithium became part of the structure (intercalated)
  - Seeing some intercalation under different cell configurations
- Uranium Dioxide behaves as a double layer capacitor Perhaps as a Supercapacitor
- Going to Dickens Recipe for Li_2UO_3

Future Work

- Use proven recipe for construction of Li_2UO_3 from Dickens while still trying reducing atmosphere method
- Add other metals and Metal oxides (e.g. Ni, Co, MnO_2,CoO_2) to the cathode formulation to enhance stability.