

Uranium Battery Development Project Final Report

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Prepared for
United States Department of Energy Portsmouth/Paducah Project Office
Acknowledgment: This material is based upon work supported by the Department of Energy under
Award Number DE-FG05-03OR23032.



June 2007

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June 2007

Abstract

This report summarizes the research funded by the Department of Energy, Oak Ridge National Labs, and the Kentucky Science and Engineering Foundation. This report briefly presents the theory behind our experimental methods and the most important experiments that were performed. This research focused on the reuse of uranium materials in lithium ion batteries. The majority of experiments involved lithium salts and organic solvents.

The potential use of depleted uranium compounds as battery or cathodes materials was the topic of this research. The electrochemical properties of uranium oxides, lithiated uranium oxides, and uranium doped lithiated nickel oxides were investigated using the electrochemical methods cyclic voltammetry (CV) and impedance spectroscopy (IS) in lithium battery salts. CV is a test used to determine if a compound can be in a reversible battery. An IS test can be used determine if a material could be used as a capacitor. This investigation mirrored the development of manganese dioxide compounds used as battery materials. Several metal oxides are known to serve as capacitors, and these materials were tested as well. In addition, a battery was constructed consisting of uranium dioxide as the cathode and lithium metal as the anode. Natural uranium compounds had to be used instead of depleted uranium due to the high cost of depleted uranium. It was cheaper to use natural uranium compounds due to the analytical costs of testing for transuranics in depleted uranium. Initially as a base case, uranium dioxide (UO_2 and U_3O_8) compounds were tested as cathodes in electrochemical cells. The CV experimental results showed that neither compound was suitable as a battery material. IS experiments were performed to see if either material could be used as a capacitor. These experiments also produced a negative result.

Lithiated uranium compounds were synthesized in under oxidizing conditions in a muffle furnace and under reducing conditions in a tube furnace. The compounds synthesized in the muffle furnace were tested for capacitance while the materials synthesized in a tube furnace was tested as a cathode material. The experiments results were negative for every compound. It was desired to produce a cathode material from a reaction of U_3O_8 and lithium hydroxide under reducing conditions.

Compounds were also synthesized consisting of lithium nickel doped with 0%, 1%, 2%, and 3% uranium. CV experiments with Lithium nickel oxide produced a fully reversible material suitable as a cathode material in a battery. However, the uranium doped compounds were not a suitable battery material. The presence of uranium appears to alter the crystal structure of the lithium nickel oxide preventing the lithium ions to travel back and forth from an anode to the cathode. As a result, the uranium doped compounds are not suitable as a battery material either.

Finally, even if lithium uranium oxides were a useful as battery materials, this research (data not shown) indicates that the resulting product due to processing costs would cost more than they would be worth. In other words, converting U_3O_8 to Li_2UO_3 would cost more than the current materials used as cathodes in state-of-the art lithium ion batteries. At the present, lithium uranium oxides do not perform well electrochemically and they would not be cost effective even if they did.

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Acknowledgements and Frustrations

The authors would like to thank the Department of Energy, The Kentucky Center for Energy and the Environment, The Kentucky Science and Engineering Foundation (KSEF), The Kentucky Research Consortium for Energy and the Environment, and Oak Ridge National Labs for funding this Research. We would like to thank Walter Tracinski of Applied Power Inc., Dr. Stephen Lipka at the Center for Applied Energy Research at the University of Kentucky, Dr. Richard Howard, and Dr. Chris Johnson of the Boeing Company for all of their advice. We would also like to express gratitude to Dr. Bill Murphy at the University of Kentucky Paducah Extension for his support in this research. We would like to thank Cerac Inc. of Milwaukee. It was the only company in the United States that would sell us uranium compounds. We would also like to thank the University of Tennessee's Material Science Program for providing analytical support for this project.

This research proceeded slowly due to the difficulty in performing research at the University of Kentucky's Paducah Extension Campus. This extension campus is hosted by West Kentucky Community and Technical College and laboratories had to be altered a lot to do research. Our original intent was to do research at USEC laboratories, but NRC regulations prohibited this activity. In addition, working with uranium materials was difficult as well. Several health and safety hurdles slowed this research down. In addition it was difficult to get lithium materials. Often supplies and materials required a nine month lead time due to demand for these materials by larger battery and/or research corporations. In addition, we were unable to acquire graduate students and post doctoral students due to our location and the way our funding was structured.

Nomenclature

CE	Counter Electrode
CV	Cyclic Voltammetry
DME	Dimethoxyethane
EC	Ethylene Carbonate
IS	Impedance Spectroscopy
LiBF ₄	Lithium tetrafluoroborate
mAh	Milli-Ampere Hours
mV	Milli volts
OCV	Open Circuit Voltage
PC	propylene carbonate
RE	Reference Electrode
UF ₆	Uranium hexafluoride
UO ₂	Uranium Dioxide
U ₃ O ₈	Uranyl Oxide
WE	Working Electrode

I. Introduction

Batteries have become an important aspect of energy storage in the United States. The battery industry has become in excess of \$14 Billion a year business and it is expected to grow as energy demand increases. The goal of this project was to develop a battery with a lithium-uranium compound based cathode. The department of energy currently houses over 10 billion pounds of depleted uranium in the form of uranium hexafluoride (UF_6) at sites in Kentucky, Ohio, and Tennessee. It has broken ground on a plant to convert the UF_6 to U_3O_8 . It was believed that the U_3O_8 could provide an inexpensive source of uranium oxides suitable as a feedstock to supply a cathode manufacturing process.

At the present, batteries with the highest energy densities are lithium-ion batteries with a lithium/carbon anode with different lithiated metals for the cathode. In general the faster a cathode can that readily can receive the electrons flowing from the anode-the better the battery. As a result, finding the best cathode is the subject of much battery research.

Currently many high performance secondary batteries consist of carbon/lithium-ion in the anode and a lithiated metal oxide as the cathode. These include lithiated manganese oxides, cobalt oxides, and nickel oxides. Figure 1 shows how a secondary battery works consisting of lithium cobalt oxide for the cathode and lithium carbon for the anode. When the battery discharges, lithium ions leave the negative electrode (anode) usually consisting of a specialty carbon and enter the crystal structure of the positive electrode (cathode) which usually consists of carbon. A battery is completely discharged when all the lithium ions leave the anode and end up “down the hill” into the cathode’s crystal structure at the lowest state of energy. As a secondary battery recharges lithium ions leave the cathode, and travel “back up the hill” to re-enter the crystal structure of the anode material. This process is called intercalation. The crystal structures of an anode and cathode must allow for ions to intercalate and re-intercalate to be suitable battery material.

Secondary batteries are rechargeable while primary batteries are not rechargeable. The typical alkaline batteries (Duracell and Energizer) purchased at retail stores are primary batteries and cannot be recharged. These companies do sell secondary batteries that can be recharged, but this is a small part of their sales. Figure 2 shows a theoretical comparison of the manganese, nickel, cobalt, and uranium cathodes.

Lithiated cobalt and nickel oxides have the best performance while lithiated manganese oxides are the cheapest and the most commonly used. In theory, a lithiated uranium oxide would have better performance (178 mAh/gram) than the manganese oxide (148 mAh/gram) and be less expensive. The markets for such a battery could be for power load leveling and military applications, and possibly hybrid vehicles. However, a uranium based battery would quite heavy and load leveling would be the most likely use. This research mirrored the development of lithiated manganese oxides commonly used in lithium-ion batteries.

Figure 1 Depiction of Lithium Ions Traveling Between the Crystal Structure of the Cathode and Anode in a Lithium-Ion Battery

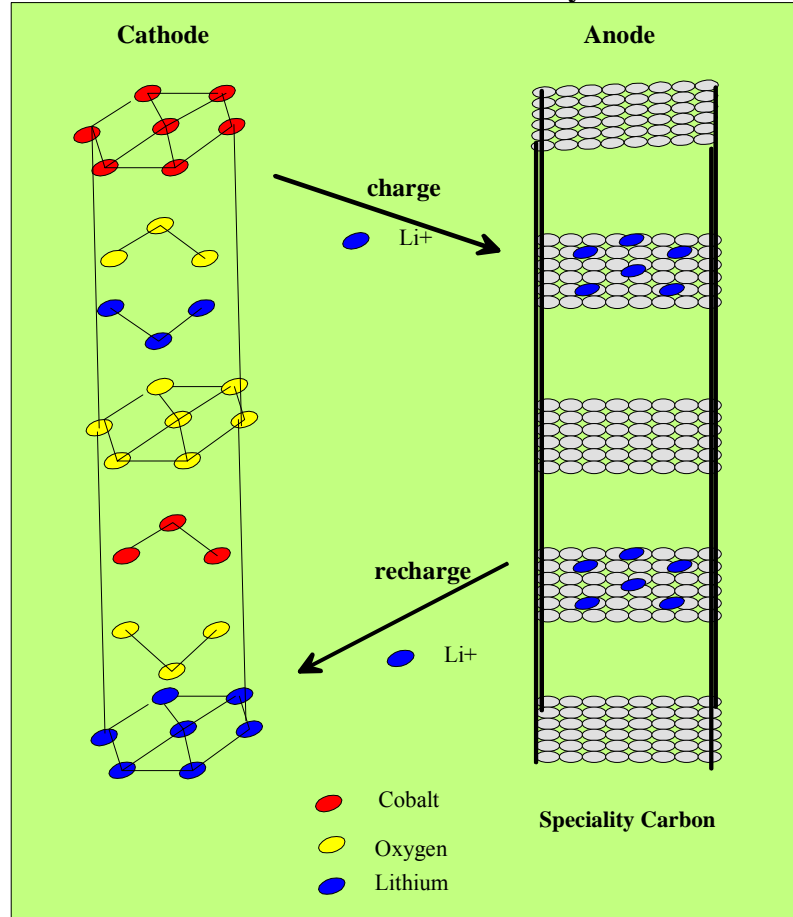
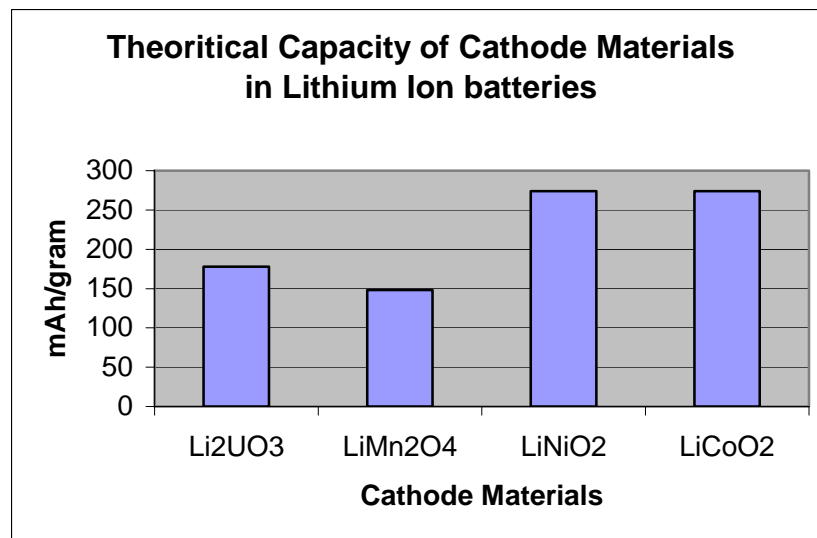


Figure 2 Theoretical Comparisons of Manganese, Nickel, Cobalt, and Uranium Oxides



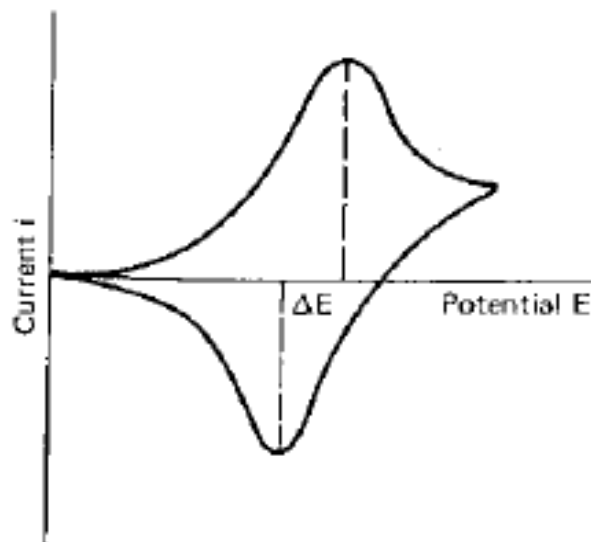
At the present, the Nuclear Regulatory Commission (NRC) has not approved the manufacture of uranium based batteries, but if they were feasible, it was believed that they could serve as load leveling batteries to replace lead acid batteries. Depleted uranium poses little health hazards with the proper engineering controls. It is a mildly hazardous material. Natural uranium contains 0.7% U^{235} which is the form of uranium that allows the production of nuclear power rods and at higher concentrations (>20%) allow the construction of nuclear weapons. Depleted uranium is only 0.1% in U^{235} concentration.

II. Methods

A. Cyclic Voltammetry

Cyclic voltammetry is an important analytical technique in electrochemistry. The voltammogram produced from the procedure traces the transfer of electrons in oxidation and reduction reactions (Bard, 2001). Figure 2 shows an ideal output of a curve of cyclic voltammetry experiment. The forward sweep is the reduction of the battery material while the reverse curve is the oxidation of the battery material. The peaks indicate at what voltages the electrons are transferred. Figure 3 shows an example of a cyclic voltammogram of lithiated nickel oxide found in the literature. This experiment was performed in 1M lithium perchlorate in propylene carbonate which is a common electrolyte used in commercial lithium battery research.

Figure 2. Example of an Ideal Voltammetry Curve
(Bard, 2001)



B. Impedance Spectroscopy

Impedance spectroscopy is an important electro-analytical technique. This technique measures the actual resistance and the capacitance (imaginary resistance) of an electrochemical cell. IS can be used to measure important parameters including reaction rates, reaction rate constants, capacitance of interface, diffusion coefficients, adsorption rate constants, and reaction mechanisms. The material parameters that can be measured include conductivity, dielectric constants, nobilities of charge, and bulk generation of charged species. IS measures impedance over a range of frequencies. IS plots impedance and frequencies on Nyquist and Bode plots. Figure 4 show an example of these plots. The plot on the left hand side of this figure is a Nyquist plot and the figure

Figure 3 Cyclic Voltammogram of Lithiated Nickel Oxide
(Journal of Electrochemical Society Vol. xx, No. xx, p. 7)

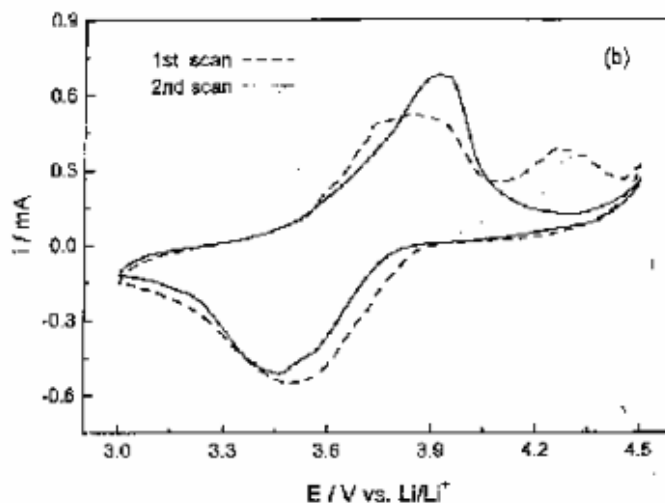
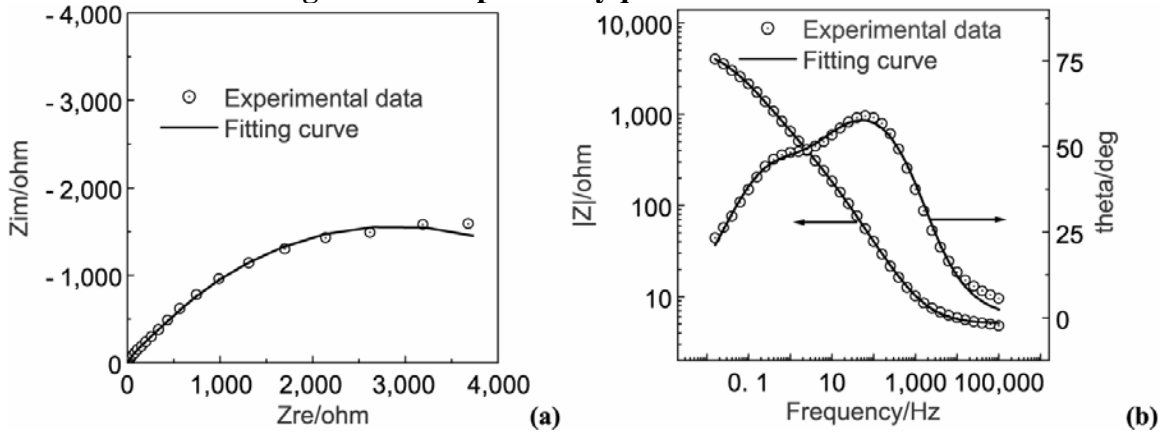


Fig. 3 Cyclic voltammograms of the $\text{Li}_{0.89}\text{Ni}_{1.12}\text{O}_2$ electrode at scan rates of a 0.1 mV s^{-1} and b 0.01 mV s^{-1} , with 1 M LiClO_4 in PC as the electrolyte

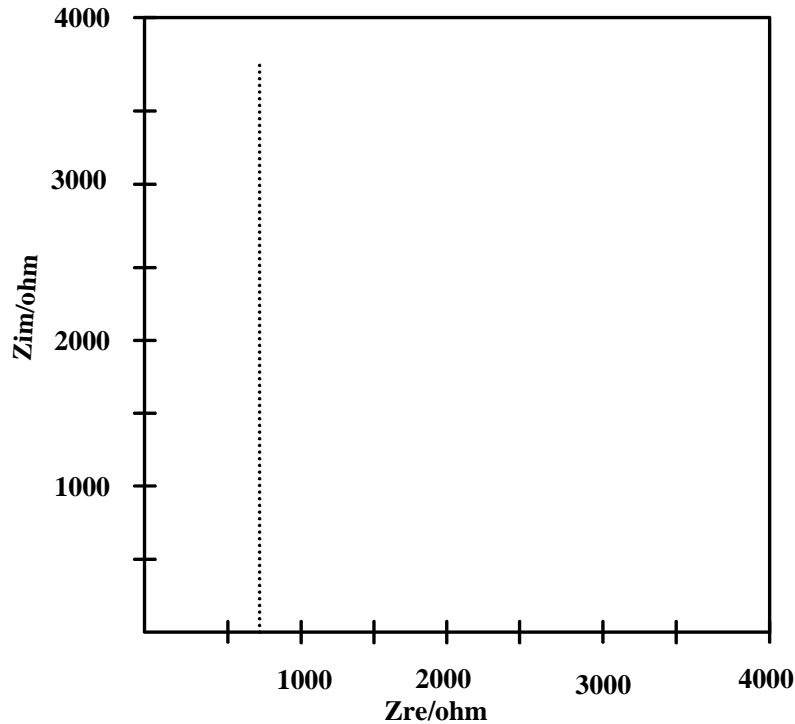
on the right hand side is a Bode plot. The Nyquist plot consists of real resistance on the abscissa and the imaginary value on the ordinate. The Bode Plot plots frequency on the abscissa and the imaginary impedance and phase angle on the ordinates. Figure 5 shows an example of IS results if the material behaves as a super capacitor. The results of a Nyquist plot of a super capacitor material should produce a vertical line.

Figure 4 Examples of Nyquist and Bode Plots



The capacitance measurement experiments are not performed in organic electrolytes. These experiments are performed in a 31% aqueous solution of KOH. The CE for these experiments is a strip of nickel. The RE is a HgO electrode. The experimental procedure involves varying the voltage ± 10 mV at different frequencies about a constant such 0.6 volts. The voltage changes from 0.610 V to 0.590 V from 64000 times a second to 0.1 times a second. The frequency response analyzer measures the resistance to this change in voltage in ohms.

Figure 5 Example of Nyquist Plot for a Super Capacitor Material



C. Methods, Materials, and Hardware

Chemicals and Materials

Uranium Oxides (UO_2 and U_3O_8), Nickel oxide were purchased from Cerac Inc. of Milwaukee, WI. Uranium acetate was purchased from Alrich Chemicals. Lithium hydroxide was purchased from Fisher Scientific. The lithium electrolytes (lithium perchlorate, lithium tetrafluoroborate, lithium hexafluorophosphate and lithium-bis(trifluoromethanesulfonyl) imide) were purchased from Lithchem Inc. Lithium foil was purchased from FMC lithium Inc.

The chemical reactions used to produce lithiated uranium oxides involved lithium oxide which was extremely corrosive at high temperatures. As a result SS330 crucibles were machined at the Southside Machine shop in Paducah, Ky. Standard reaction crucibles quickly deteriorate under high temperatures in the presence of lithium oxide.

Exmet Inc. supplied all the expanded nickel, stainless steel, and copper used as the backing for the WEs. Celgard Inc. supplied all the necessary membranes used in the Hohsen electrochemical cell.

Software and Hardware

All electrochemical experiments were controlled using Scribner Electrochemical Software. A Dell Pentium III computer was used to run the software. A Princeton Applied Research (PAR) 273A potentiostat was used to control CV experiments. A Solartron 1250 RFA was used as to measure the impedance of the cells. Experiments were performed in a Hohsen electrochemical cell or in a 50 to 100 ml flooded cell. A Vac Atmospheres Glove box (Manufactured in 1985) was used to maintain a low ppm atmosphere of water vapor and oxygen. A fisher scientific tube furnace was used to synthesize lithiated uranium oxide compounds required a reducing atmosphere. A Fisher Scientific muffle furnace was used to synthesize compounds requiring oxidative atmospheres.

D. Construction of UO_2 Pellets

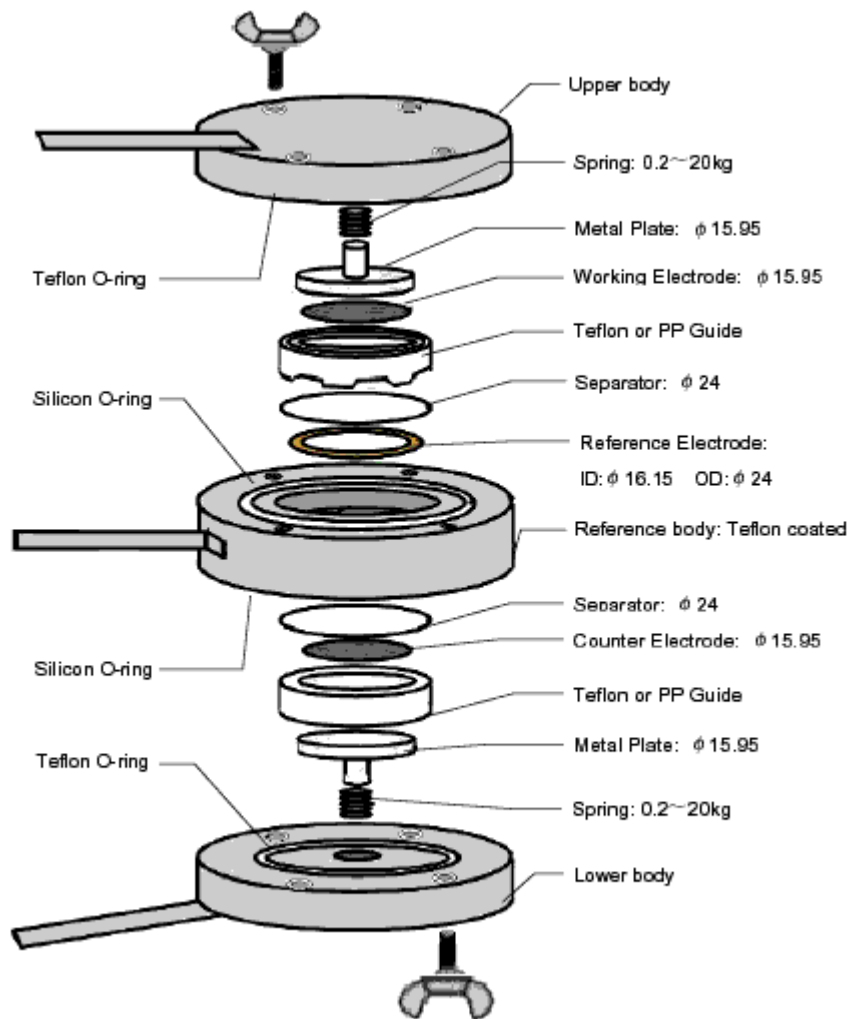
For some of the initial CV and IS electrochemical experiments, a UO_2 pellet electrode was constructed. The electrode is composed of uranium oxide, PDVF (binder), and a carbon material, which serves as a conductive filler. The pellet is positioned between two layers of expanded nickel metal, which serve as current collectors, and welded to a nickel wire. Fabrication involved pressing the materials together and heating at a temperature high enough for some melting to occur in the binder. Once the pellet was constructed, it was inserted in a hollow tube and encased in such a way that only the UO_2 electrode material was exposed at the bottom of the tube. Electrical connection was made with a nickel wire inserted into the electrode. The manufactured UO_2 electrode was used for cyclic voltammetry experiments with a nickel counter electrode in a 1M LiClO_4/PC organic electrolyte. However, since the results of these experiments were negative (no electron transfers) it was decided to try other methods.

E. Holsen Electrochemical Cell

Figure 6 shows a schematic of the Holsen electrochemical cell. The procedure for constructing the working electrode for this cell is shown stepwise below. Pure lithium foil was used for the CE and RE. Hole punches were used to make the electrodes. The instructions below are for UO_2 , but similar methods are used for making other working electrodes. Graphite (5 to 10%) was added to the mix to improve electron conductivity. DuPont Teflon TEFE 30 (3%) was added as a binder. Polypropylene and other polymer separators were purchased from Celgard Inc. Only separators used for secondary lithium-ion batteries were used in these experiments. These separators wetted nicely. It should be noted that materials should be processed while they are hot (around 100 °C or more).

- Mix 5.4 gram UO_2 to mortar and grind with pestle for about 15 minutes
- Add 0.6 gram graphite and grind for another 15 minutes
- Add 300 ml liters of PTFE 30
- Place in oven for 25 minutes at 130 C
- Remove from oven grind for 15 minutes with oven mitts
- Place back in oven for another 25 minutes
- Remove from oven grind another 15 minutes
- Place back in oven for another 25 minutes
- Remove and place material on weigh paper
- Cycle through a pasta maker until less than 0.5 mm in thickness
- Punch out 14 mm diameter nickel mesh and UO_2 pellet (weigh separately)
- Place nickel mesh on top of UO_2 “fabric” and press for 30 minutes with a 12 ton press between layers of weigh paper or Mylar
- Weigh again to subtract out any UO_2 lost on weigh paper.

Figure 6 Diagram of the Hohsen's Cell



F. Uranium Oxide Battery Construction Procedure

The cathode was made by mixing 1.000 g of UO_2 , 0.200 g of carbon, 0.100 g of TFE, and approximately 1 ml of solvent. The components were ground in a mortar and pestle until uniform and somewhat plastic. The cathode was transferred to a die $1 \frac{1}{4}$ inches in diameter and pressed at 3 tons. The resulting cathode was then cookie cut into 3 disks, each 0.637 inches in diameter.

Each cathode disk was weighed and measured for thickness then placed in the center of the cup of the 2032 cell in which a nickel grid had been placed. A single polypropylene separator was placed on top and the seal gasket ring was added holding both the cathode and separator in place. At this point the cathode was transferred to the VAC glove box for additional processing.

An electrolyte consisting of PC:DME in a 1:1 ratio (propylene carbonate: dimethoxyethane) with 1 M LiBF₄ (lithium tetrafluoroborate) was added to the separator/cathode cup. The lithium pellet was then placed on top of the separator with a nickel backing plate over it. A stainless steel wave washer was added, then the top cell cover. The voltage was checked prior to pressing closed. The anode was prepared by cookie cutting the lithium into disks. The resulting volume equated to a capacity of approximately 226 mAh for the anode. A nickel backing plate and spring were added to allow for volume changes during discharge or cycling.

After crimping, the cell was rechecked for voltage. It was noted that with the first cell a sliver of steel was peeled off the case during crimping. This acted as a short and had to be removed. Although the sliver was hard to observe, the voltage check indicated the problem. This had little effect on the capacity of the cell but did result in a significant voltage depression. The recovery of some of the OCV (open circuit voltage) can be observed in the first ten minutes of the discharge test prior to the start of the actual discharge.

G. Synthesis of Lithiated Uranium Compounds

Lithiated uranium compounds were synthesized from either UO₂ or U₃O₈. The procedure to make lithiated uranium oxides are shown below.

Reactions with UO₂

The following reaction and procedures were used to produce Li₂UO₄. The product was synthesized to be tested for use as a capacitor material. It was not suspected to be suitable as a battery material due to the valence state of the product. However it was tested for its charge capacity for its potential as a super capacitor.



Rxn 1:	UO ₂	1.10g (4.1mmol)	Rxn 2:	UO ₂	1.38g (5.2mmol)
	LiOH•H ₂ O	0.35g (8.3mmol)		Li ₂ CO ₃	0.38g (5.1mmol)

Reactants were ground together with a mortar and pestle, transferred to separate quartz crucibles, and calcined according to the following profile.

- Step 1: Heat to 450⁰C at 2⁰C/min
- Step 2: Soak at 450⁰C for 1 hour
- Step 3: Ramp to 650⁰C at 2⁰C/min
- Step 4: Soak at 650⁰C for 3 hours
- Step 5: Turn oven off and allow to cool overnight.

The 450°C soak allowed the distribution of molten LiOH and a more complete reaction. Li₂CO₃ melts about 720°C, but in practice, thermodynamics drives this salt to react as low as 375°C with metal oxides. Further, molten Li₂CO₃ is highly viscous (so no advantage to an infusion step), and the metal oxide reactivity dictates reaction temperature.

The products of reactions 1 and 2 were flour-like orange-gold powders.

Reactions with U₃O₈

Uranyl oxide is the natural composition of spent uranium, and the most thermodynamically stable oxide, therefore it is the preferred choice of starting material. The objective of the following experimental matrix was to prepare Li_xUO_n species from U₃O₈ that contain some U(IV). Only these compounds will allow Li de-intercalation. The product of chemical reaction 2 is the most likely product to be active as a battery material. Reactions 3 and 4 were used mixed in a mortar and pestle. Reaction 2 was performed in a tube furnace. The hydrogen gas came from a gas mixture (purchased from Air Gas Inc.) consisting of 95% argon and 5% hydrogen. A mass flow controller controlled the flow of gases into the tube furnace. Argon was used to purge the reactor for three hours before the temperature was raised in the furnace. After the reaction ended, valves were switched (a gas manifold was constructed to facilitate this) again to purge the system with Argon gas as the system cools. Oxygen was not allowed into the system. The material was removed from the furnace and quickly placed into the glove box for storage.



Rxn 3:

U₃O₈ 1.70g (2.04mmol)
LiOH•H₂O 0.17g (4.05mmol)

Rxn 4:

U₃O₈ 1.62g (1.94mmol)
LiOH•H₂O 0.49g (11.7mmol)

The initial testing results were quite negative. As a result, the material was re-grinded in the mortar and processed in the furnace as many as three times before it was tested. This was quite expensive since it required a tank of 5% hydrogen gas for each round in the glove box.

H. Health and Safety

The major health risk hazard is the inhalation of uranium dust particles. Uranium dust has been shown to cause lung cancer. Masks were worn while uranium dust was handled. All mixing and handling of the uranium powders performed in a glove box or under a hood. Uranium compounds were mixed with a binder (usually Teflon in solution) and graphite. Once the uranium compounds are stabilized with a binder the risk of dust inhalation greatly diminishes.

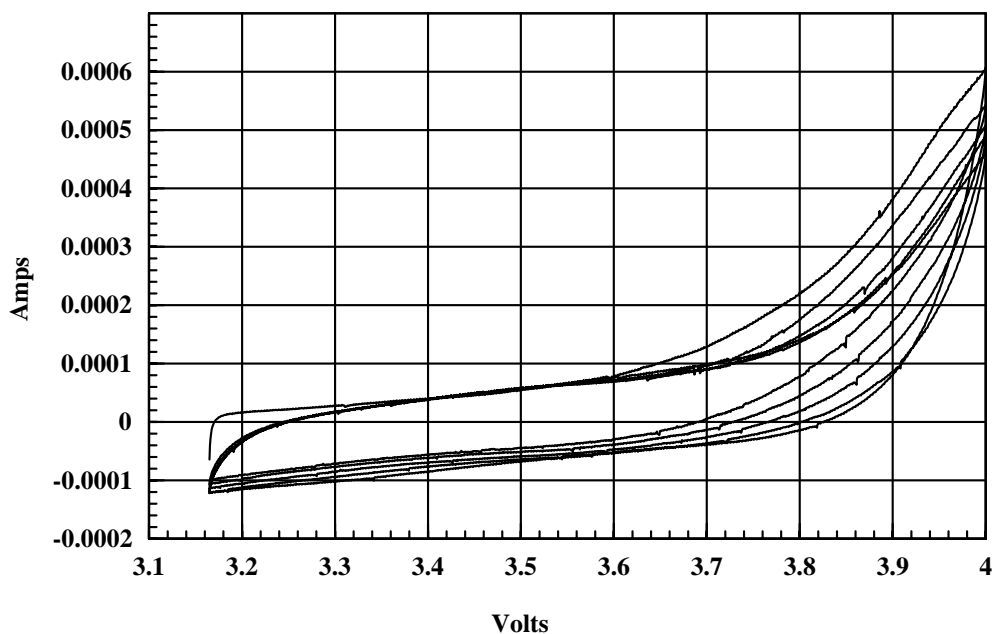
III. Experimental Results and Discussion

A. Electrochemical testing of Uranium Dioxides

Uranium dioxide was tested in a Holsen electrochemical cell. UO_2 was the WE, and lithium metal serves as both the CE and RE. The three different electrolytes (1 M Lithium Perchlorate 1 M Lithium Tetrafluoroborate, and 1 M Lithium Hexafluorophosphate in a 1:2 mixture of DMC/EC by volume) were prepared by LithChem and stored in the argon atmosphere of VAC glove box to maintain purity. Figure 7 indicated that uranium dioxide was not an active battery material. Alternatively the results indicated that the material could potentially serve as a capacitor in an electrochemical device. There are no electron transfers occurring in the charge and discharge of the material in this test. This indicates that the material is simply storing electrons on its surface without ever seeing an electron transfer between the materials via the electrolyte solution. These experimental results are typical of the CV tests performed on uranium dioxides. This also includes the CV tests on U_3O_8 WE. No electrons were observe to transfer in these experiments either.

Figure 7 Cyclic Voltammetry of UO_2 in Lithium Battery Salts

WE in 1 M Lithium Tetrafluoroborate in a 1:2 mixture of DMC/EC by volume, CE = lithium metal = RE.

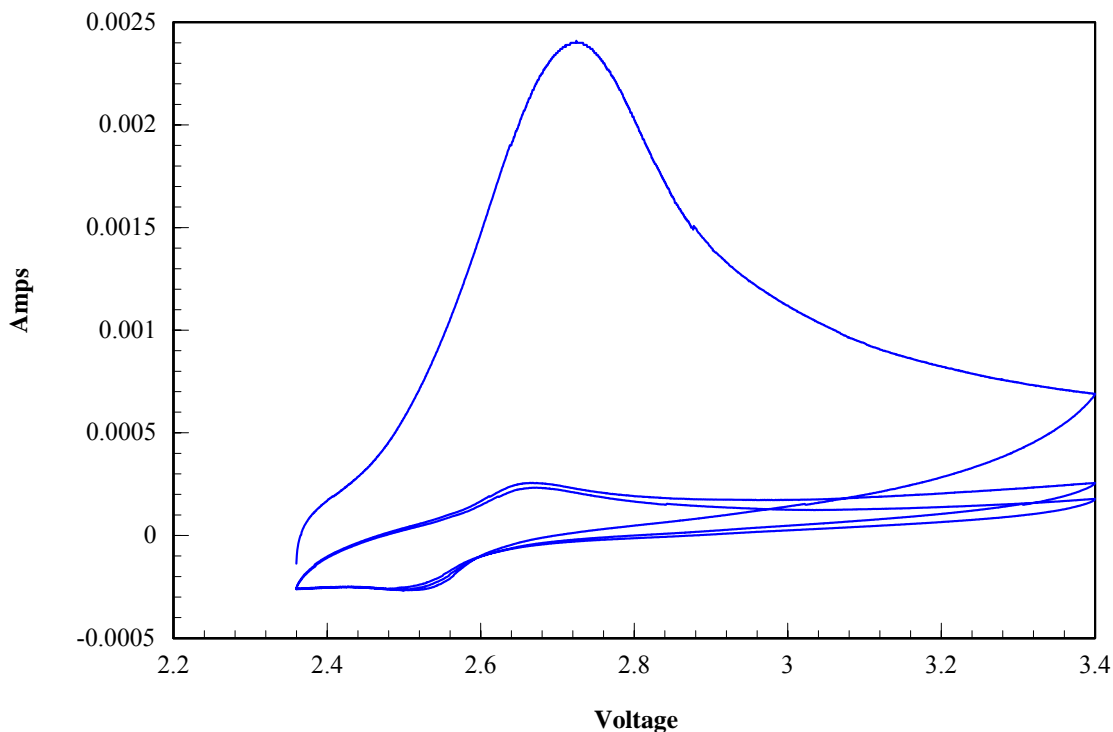


B. Lithium Uranium Oxide Tests

Figure 8 shows the cyclic voltammetry experimental results for lithium uranium oxide in a flooded cell inside the glove box. This material was suspected to be Li_2UO_3 , but the real stoichiometry was unknown. It can be described as $\text{Li}_x\text{U}_y\text{O}_z$. The x-ray diffraction data is not shown here but it showed that lithium and uranium were present. This material was the result of three grindings and three furnace treatments. Other experimental results exist for material that went through the furnace once and twice, but

the material used for figure 8 produced the best results. The forward scan indicates that lithium is being removed from the WE however the lithium is not re-intercalating into the structure. In essence, lithium is being stripped from the WE, but not re-inserting into the material. The current increased on the forward sweep in the first cycle by over five fold. However, the reverse sweep showed little promise of reversibility. The results seem to indicate that the crystal structure was improved by the number of grindings and furnace treatments by the increased current output. Perhaps it is feasible to find a method that would produce a suitable crystal structure that would allow intercalation and re-intercalation. However, this would be another research project.

Figure 8 Cyclic Voltammetry of Lithiated Uranium Oxide



C. CV Experiments on Uranium Doped Lithium Nickel Oxide

Figure 9 below compares the CV curves between lithium nickel oxide and 2% uranium doped lithium nickel oxide. The lithium nickel oxide material synthesized at UK Paducah is very similar to curves found in the literature. The curve shows an electron transfer reaction on the forward and reverse sweeps. However, the uranium doped compound does not show any electron transfer. There are no “humps” in the curves that indicate the electrons were transferred. Apparently charges are stored and/or chemical reactions are occurring on the surface of the material without any electron transfer. The large uranium atom appears to alter the crystal structure of the nickel oxide material preventing the lithium ions from intercalating and re-intercalating.

Figure 9 Cyclic Voltammetry of LiNiO₂ and 2% Uranium Doped Nickel oxide

LiU_{0.02}Ni_{0.98}O₂ (RE and CE = Lithium, electrolyte was Lithium perchlorate in 1:2 PC/DMC, Scan rate = 0.1 mV/sec)

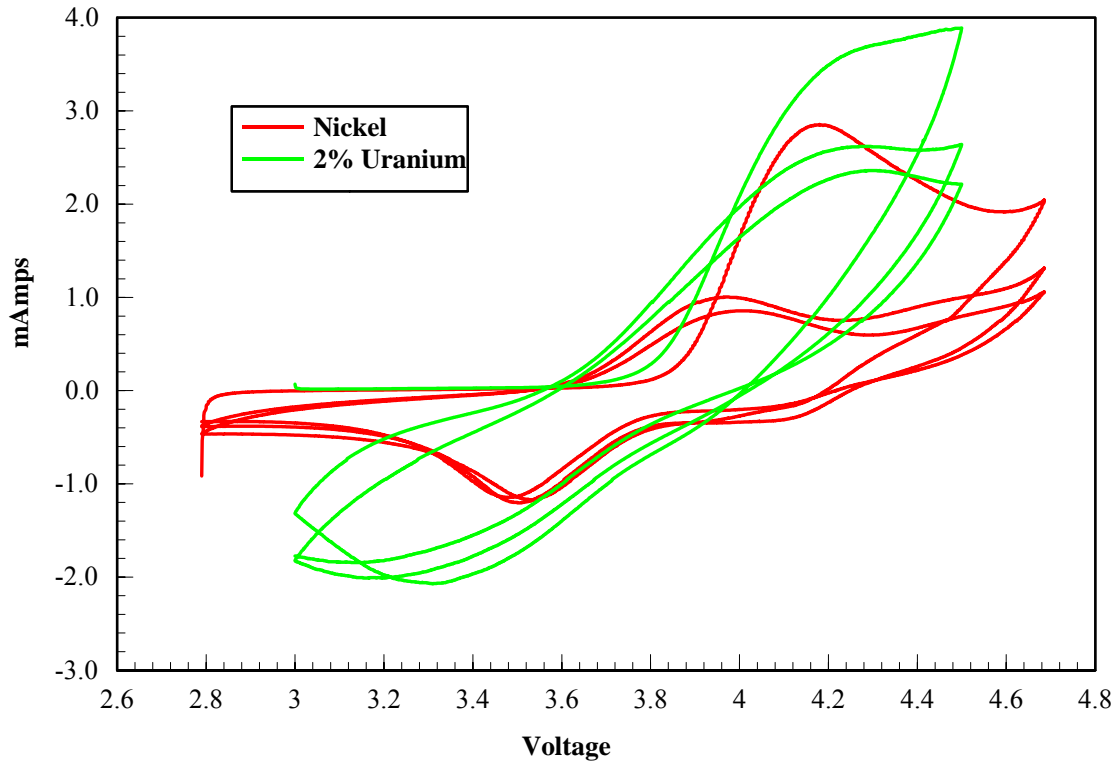
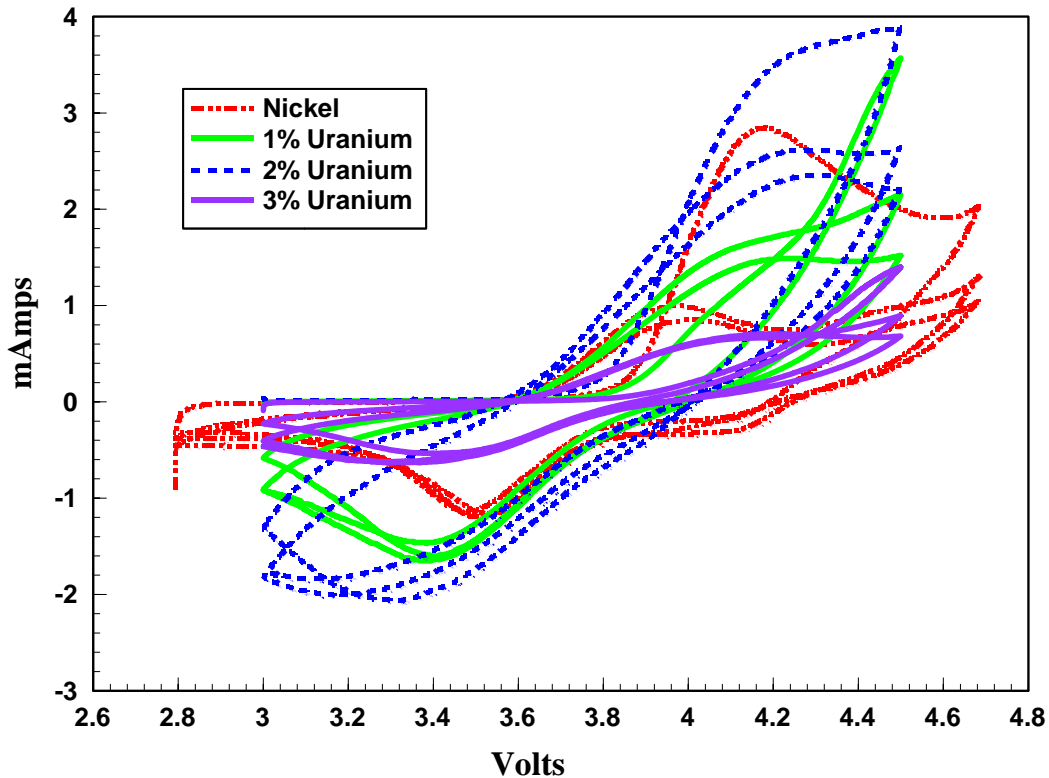


Figure 10 compares the lithium nickel oxide with all three compounds that were doped with uranium. The results are quite similar. There were no electron transfers in any of the uranium doped compounds. The uranium atom appears to deform the crystal structure making the material useless as a battery material.

Figure 10 Comparisons of CV tests of LiNiO₂ Three Different Uranium Doped Compounds (RE and CE = Lithium, electrolyte was Lithium perchlorate in 1:2 PC/DMC, Scan rate = 0.1 mV/sec)



D. Experimental Results for a Uranium Dioxide Battery

All three battery cells were removed from the VAC glove box and the voltage rechecked. They were then placed in a test chamber for safety. The OCV was monitored for 10 minutes before the actual discharge test was initiated. The cells were discharged using a Maccor battery test system at 1 mA to 2.0 V. Since the surface area was approximately 2 cm² the current densities used was 0.5 mA/cm². After the initial discharge to 2 V the cells were recharged then again discharged for 2 cycles at a current density of 0.5 mA/cm². Figure 11 shows the charge and discharge curve for a uranium dioxide-lithium battery. The anode is lithium metal and the cathode is uranium dioxide. The results of this test show that a uranium dioxide battery would be a very poor one. The battery discharges very quickly even at a low rate of 1 mA at 2.0 Volt load. The voltage drops suddenly as soon as it is discharged. The voltage drops from 3.8 volts to 2.5 volts within 10 minutes. This indicates that the UO₂ has a very low storage of charge capacity. Figure 12 shows a discharge for a typical lithium-ion battery. The voltage drops (look at the 20 °C curve) from 2.9 volts to 2.5 volts in 7 hours. This comparison demonstrates that UO₂ would not be a useful battery material.

Figure 11 Charge and Discharge Curves for a Uranium Oxide Battery

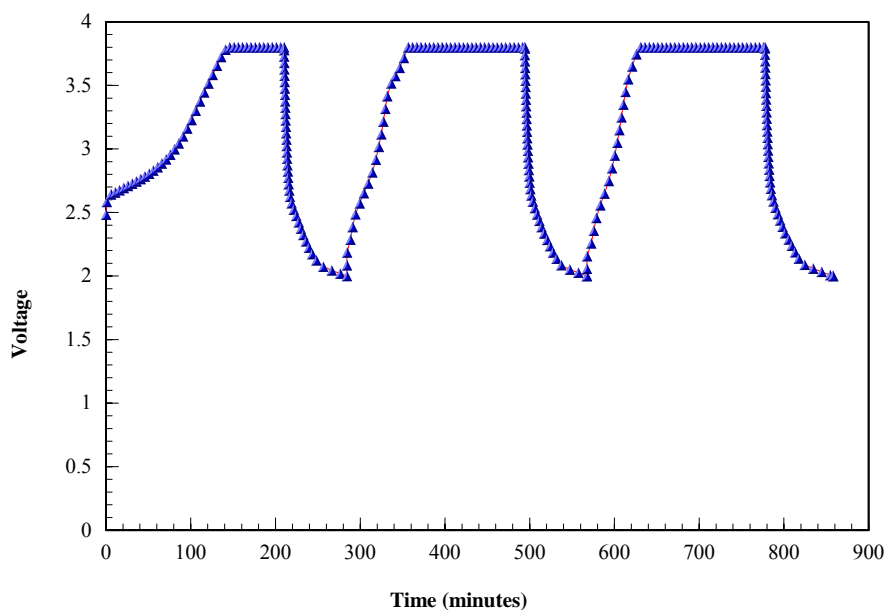
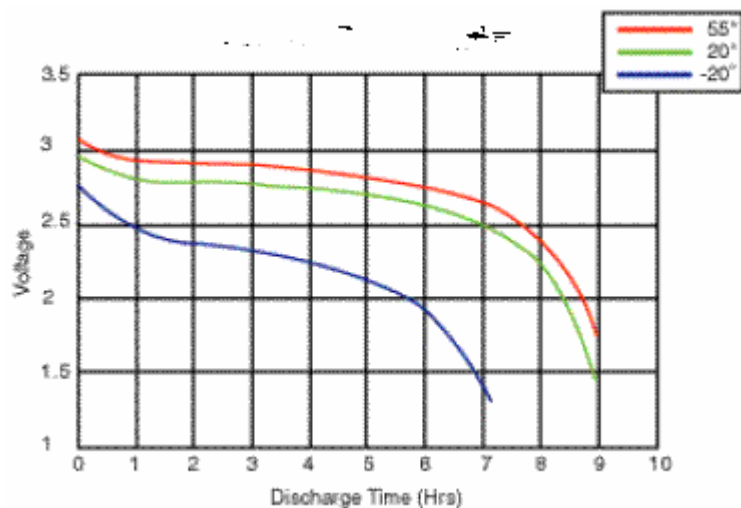


Figure 12 Discharge Curves for a Lithium Ion Battery
(<http://www.mpoweruk.com/performance.htm>)

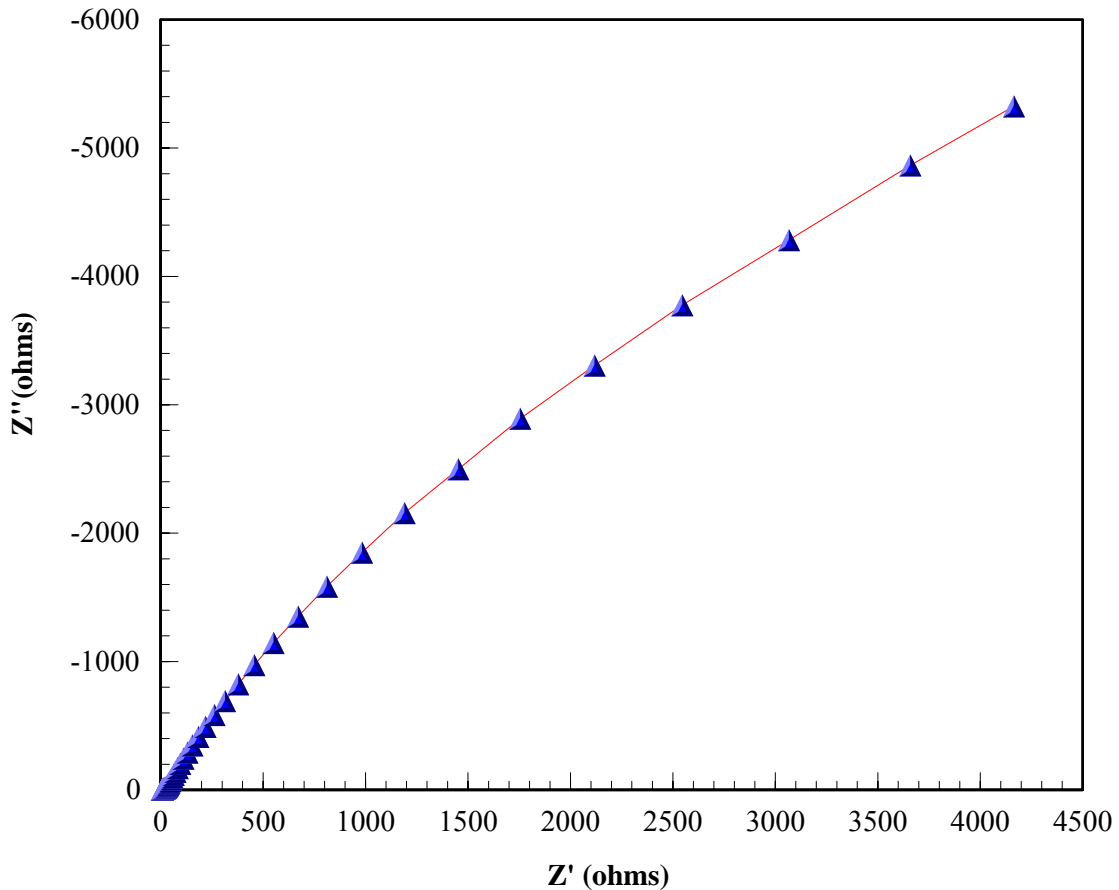


E. EIS Experiments

Electrochemical impedance spectroscopy (EIS) is required to determine if a material behaves as a capacitor. Figure 13 shows the result of an EIS test on U_3O_8 . The test was made from 63,000 hz to 0.001 hz at a set constant voltage load +/- 10 mV perturbation to the system. This curve shows a typical experimental curve performed on this material. Several experiments were performed in a range of minus 0.6 volts to plus 0.6 volts.

Eight separate experiments were performed on the same WE. Figure 13 demonstrates that U_3O_8 can not be used as a capacitor. A vertical line (or close to it) is desired for a material that potentially could be used as a super capacitor. None of the materials that were synthesized or tested in this research effort produced curves characteristic of a super capacitor material. Initially UO_2 and U_3O_8 showed some potential based on their CV experiments. However, it turned out to be a negative result when they were tested further using IS techniques as demonstrated in figure 13. There are many more curves like figure 13 that have been generated in this research project.

Figure 13 An Impedance Spectroscopy Experiment on U_3O_8



IV. Conclusions

Uranium has shown to be an excellent material for building bombs and generating power, but there does not appear to be much of a use as a battery material or any other electrochemical material. Uranium oxides are not useful as battery materials or as capacitors in the solutions that these experiments were performed. The lithiated uranium oxides synthesized in this research project would not allow lithium ions back into their crystal structures. As a result, these materials are not useful as battery materials either. Lithium nickel oxides were doped with uranium and instead of enhancing the performance of the materials; the uranium deformed the crystal structure preventing lithium ion intercalation. Previous research has shown that uranium enhanced the performance of lithium manganese oxides at 1 and 2% concentrations.

Finally, even if lithium uranium oxides were a useful as battery materials, this research (data not shown) indicates that the resulting product would cost more than they would be worth. In other words, converting U_3O_8 to Li_2UO_3 would cost more than the current materials used as cathodes in state-of-the art lithium ion batteries. At the present, lithium uranium oxides do not perform well and they would not be cost effective.

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